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Help

Summary

Wire Development Group (WDG)

Research Towards Advanced HTS Wire Technologies

2004 DOE Annual Peer Review

July 27-29, 2004

Washington, DC

Argonne National Laboratory

American Superconductor™

Los Alamos

Superconductivity Technology Center

OAK RIDGE NATIONAL LABORATORY

U. S. DEPARTMENT OF ENERGY

University of Wisconsin-Madison

WDG Scope

Founded: 1991

Mission:

Develop the materials science base for advanced HTS wire, maintaining and extending US world leadership

Program Approach:

- Leverage unique resources and competencies of a world leading HTS company, three major DOE labs, and a key university program
- Focus on developing high performance (high I_c) advanced HTS wire in a multi-institutional collaboration

13 year experience base for effective co-operation and progress

Outline

Overview, Research Integration	Alex Malozemoff (AMSC)
2004 Results: Pinning in 2G Wire	Leonardo Civale (LANL)
2004 Results: 1G wire Processing	Eric Hellstrom (UW)
Current Limiting Mechanisms, 2004 Performance and Results, 2005 Plans	David Larbalestier (UW)

FY04 Funding Challenges and WDG Response

Due to DOE budget problems:

- Funding to UW for 1G work cut for ½ year, only partially restored
- Funding to ANL WDG work cut almost completely
- Funding to LANL is running out

Response: We regrouped, focused on a more limited range of topics, continued to make progress

Wire Development Group strongly recommends increased funding in order to fulfill its mission

WDG ranked #1 in Strategic Research at last year's Peer Review; has capability to continue worldwide leadership of advanced HTS wire research

2004 Performance: WDG Financial and Legal Framework

‘No-funds exchanged’ CRADA agreements between team members:

AMSC (CRADA support by AMSC)	**$ 535K**
LANL	**$ 375K**
ORNL	**$ 225K**
UW	**$ 262K (reduced)**
ANL	**$ 80K (reduced)**
Total DOE supported	**$ 942K**

IP agreement protects confidential ideas

AMSC invested $2.3M in its FY2004 in 1G R+D and $3.3M in 2G R+D: strong commitment to HTS wire technology leadership

2004 Performance: Implementation

Principals:

Huang, Rupich, Otto, Malozemoff	AMSC
Holesinger, Civale	LANL
Feenstra	ORNL
Maroni	ANL
Larbalestier, Hellstrom, Cai	UW

Other Contributors:

Fleshler	AMSC
Abraimov, Feldmann, Jiang, Polyanski, Yuan, Liao, Song, Kim	UW

Implementation:

- Meetings, teleconferences, sample exchange, round robins, trimesterly planning
- Focus on critical technical issues and improved I_c wire performance
- AMSC provides high quality wire precursor for further processing or characterization
- Multiple publications
- 2G activity initiated – important new results on 2G pinning
- Significant progress achieved on 1G plan

Research Integration: WDG Leverages Complementary Competencies

AMSC	Wire process innovation, materials science expertise Product development and manufacturing Customer input to wire specifications
LANL	Analytical Electron Microscopy, electrical characterization Small-scale powder and wire processing
ORNL	2G processing and characterization expertise
ANL	Chemistry and reaction expertise Unique characterization: Raman, Adv. Photon Source
UW	Electrical and magnetic characterization; spatial imaging Theoretical understanding of current limiting mechanisms Special processing capabilities – overpressure

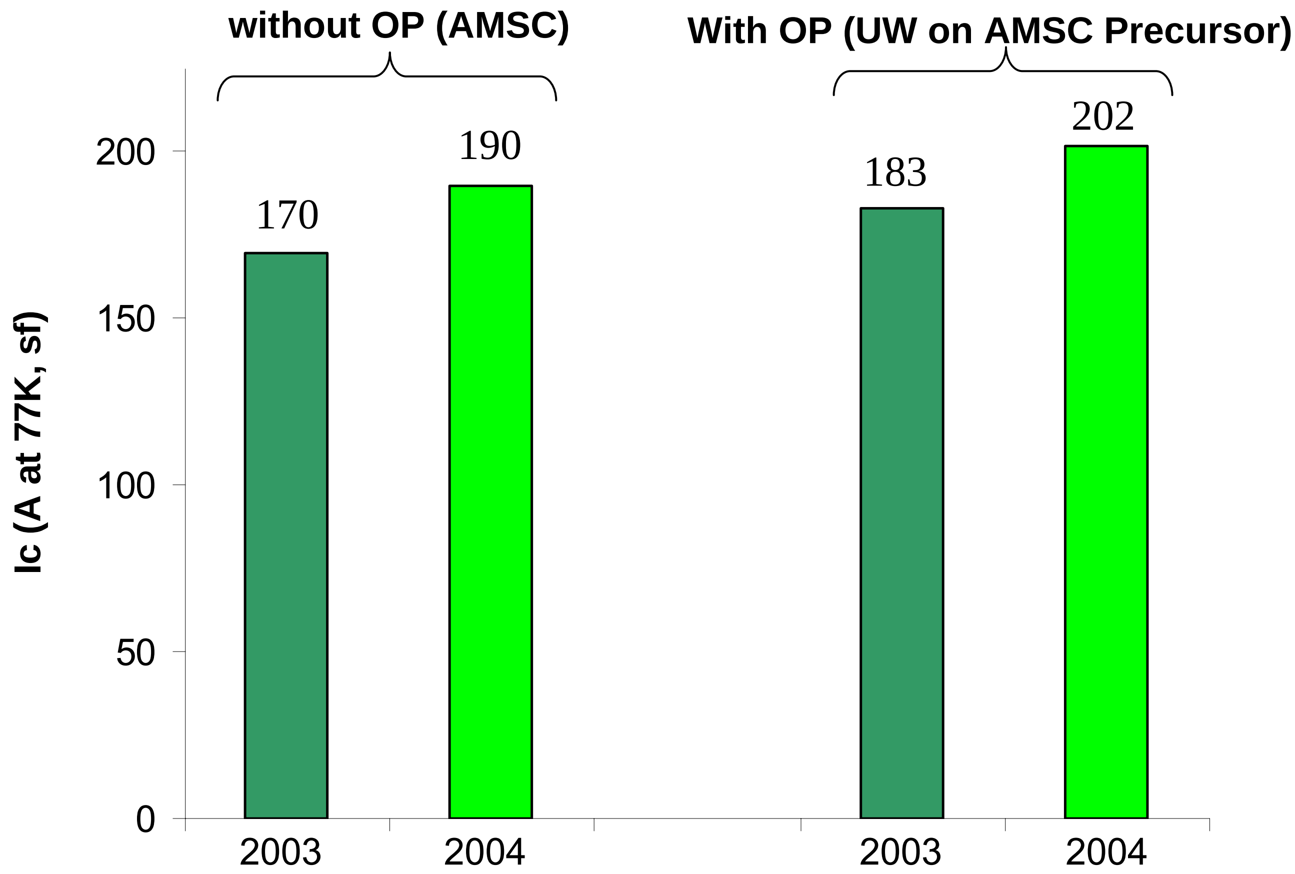
Altogether the world's most powerful effort advancing HTS wire technology

2004 Performance: Progress Against Objectives

1. **Improve understanding of BSCCO-2223 formation**
   - ✓ **Heat treat quenching and characterization at UW on AMSC precursor identify new current enhancement mechanisms**
   - ✓ **AMSC uses information to achieve new short-length 1G record without OP: 190 A (77 K)**
2. **Evaluate routes to increasing BSCCO-2223 phase purity in 1G wire**
   - **Postpone due to budget cuts**
3. **Develop scanning laser microscopy (LTSLM) to identify local dissipation in 1G and 2G**
   - ✓ **Equipment delayed, but results on 2G conductor obtained at Erlangen – correlation of dissipation and local grain boundary orientation observed**
4. **Evaluate overpressure processing (OP) for 1G wire production**
   - **Plan readjustment:** Focus on OP performance improvement.
   - ✓ **New 1G record 202 A (77 K, sf) with OP achieved at UW on AMSC precursor.**
5. **Initiate 2G pinning characterization work**
   - ✓ **Field-angle I_c characterization and TEM at LANL on AMSC 2G wire reveals correlated pinning from planar grain structures dominating.**
   - ✓ **Reduced field angle dependence was found with Y-doping and short processing in AMSC and ORNL 2G *ex-situ* films; nanodot pinning effect identified**

Impact: WDG progress and knowledge base underlies successful AMSC production, achievement of >1000 meter-long 148 A (77 K) 1G HTS wire

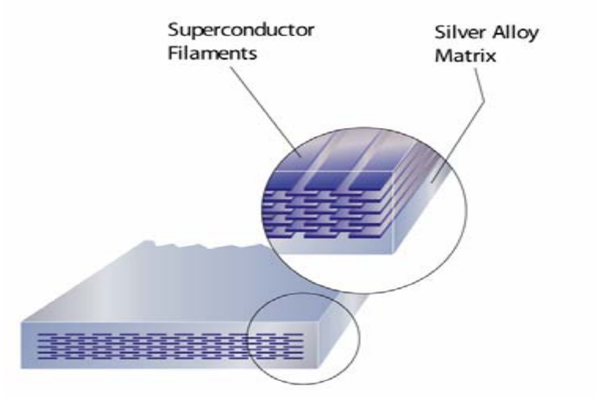
New WDG R&D Records on Short 1G Wires
(as of July 2004)



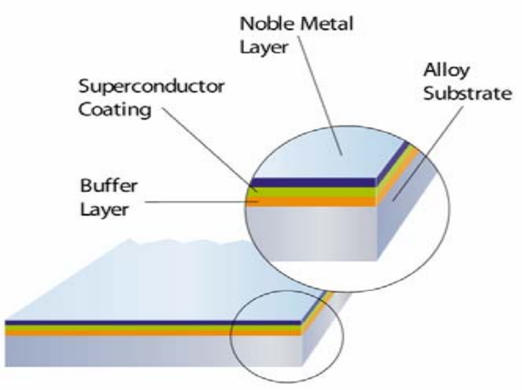
Ongoing 1G wire progress: laying the base for the future

The Context: Status and Economic Viability of HTS Wire

1G (BSCCO)



2G (YBCO)



- AMSC manufacturing first generation (1G) multifilamentary composite BSCCO wire @>1,000,000 m/year
- Commercial sales
- Targeting \$50/kA-m (77K,sf) price-performance
- ≥125 A (77 K, sf) in 4.2x0.21 mm^2 equivalent to 295 A/cm-width, continuing to advance

- To broadly replace copper, <\$25/kA-m required
- Need advanced technology with higher I_c, lower cost – solution is 2G
- Major progress in establishing process capability for second generation (2G) YBCO coated conductor confirms scale-up strategy
- Multiple years still required for substantial (million meter/yr.) production output

1G HTS Wire: Competitive Context

Reactivated focus on 1G wire overseas

- Sumitomo Electric (SEI) increases performance up to 130 A using overpressure (HIP) processing (developed in parallel to WDG work), invests in major HIP production facility.
- Japanese "WDG" founded, supporting SEI program
- InnoST (China) enhances performance, supplies first Chinese cable project

1G wire critical to all commercial-level prototype projects during next 3-4 years: it is the "silicon" of the HTS wire industry!

Ongoing 1G R+D will be required to maintain US lead

Future Directions of WDG

- 1G wire process continues to offer significant opportunities for improvement and understanding

- Improvement of 2G pinning critical to coil applications
  - *Characterization and understanding of unusual $J_c(B,T,\theta)$*
  - *New pinning mechanisms to enhance J_c*

- Characterization techniques and current limiting mechanisms have much in common between 1G and 2G
  - *Leverage insights*

For FY05, we propose a balanced program on both 1G and 2G

Conclusions

- Wire Development Group is a unique example of research integration
  - *Worldwide leadership in the materials science of advanced HTS wire*
- 1G wire an ongoing critical element of DOE program and needs to be supported, at least at a critical mass level
- 2G wire research successfully transitioned into the WDG

Vortex pinning mechanisms in MOD-based coated conductors

L. Civale, B. Maiorov, T. Holesinger

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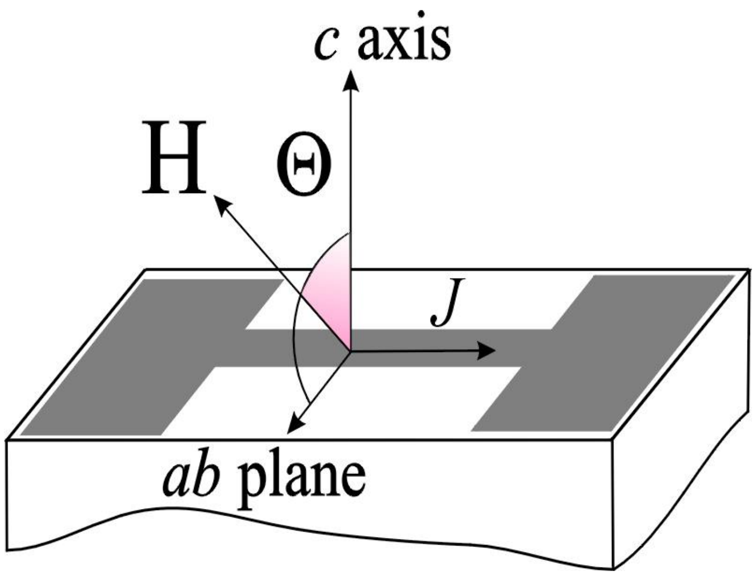
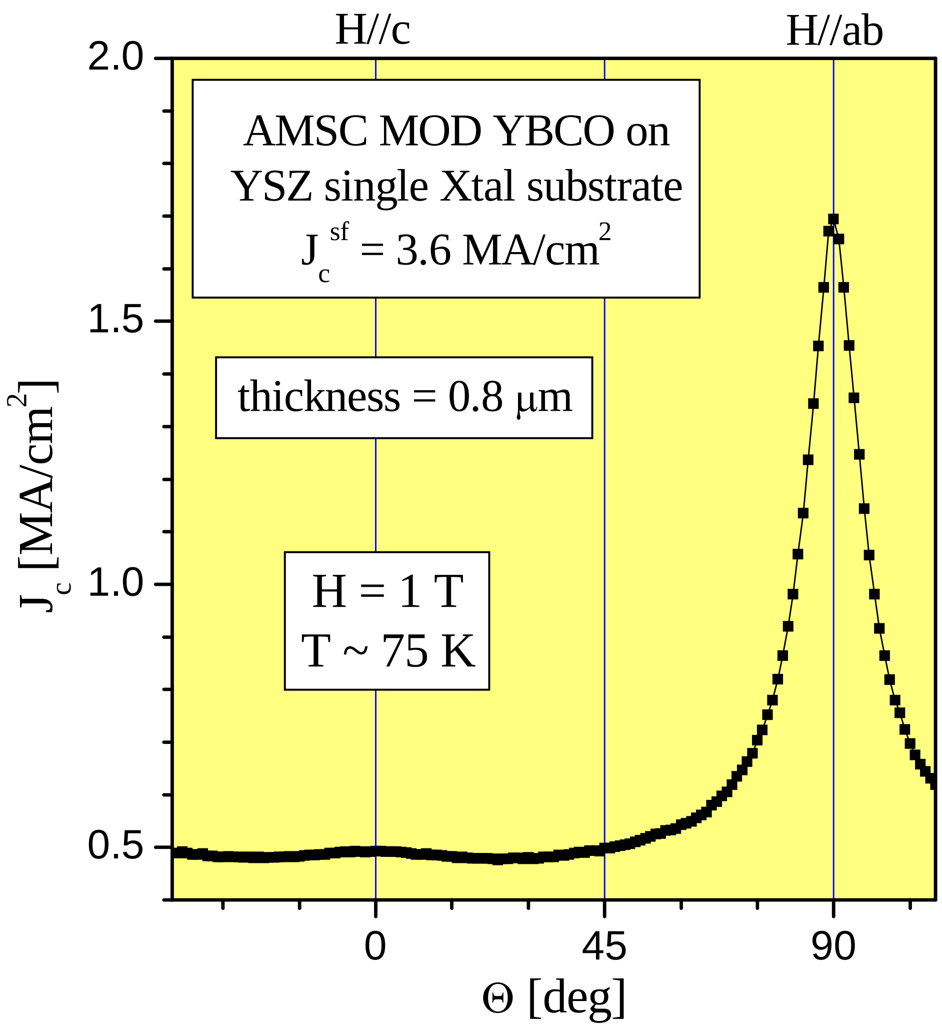
We use the field, angular and temperature dependence of J_c to identify pinning mechanisms and regimes



H ⊥ J always
(maximum Lorentz force)



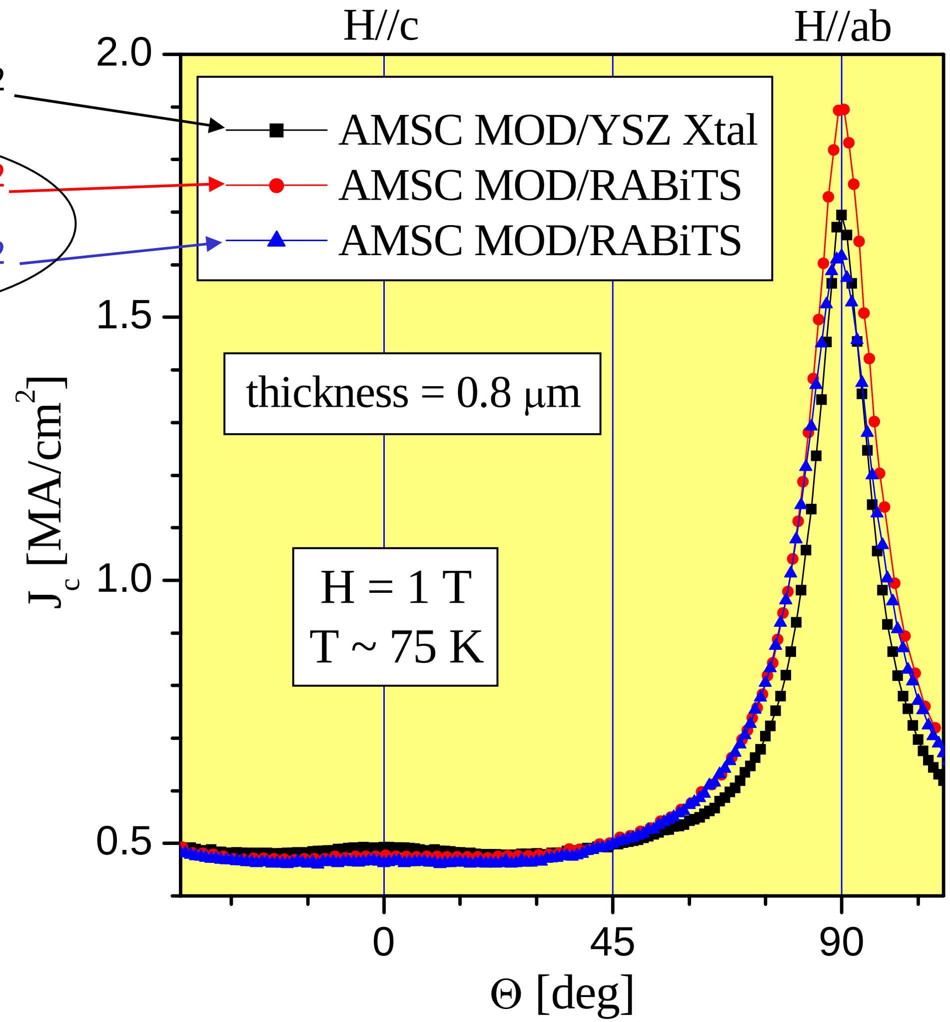
The angular dependence of J_c is very reproducible and similar for MOD films on single crystal substrates and NiW tapes

J_c^{sf} = 3.6 MA/cm²

J_c^{sf} = 3.3 MA/cm²

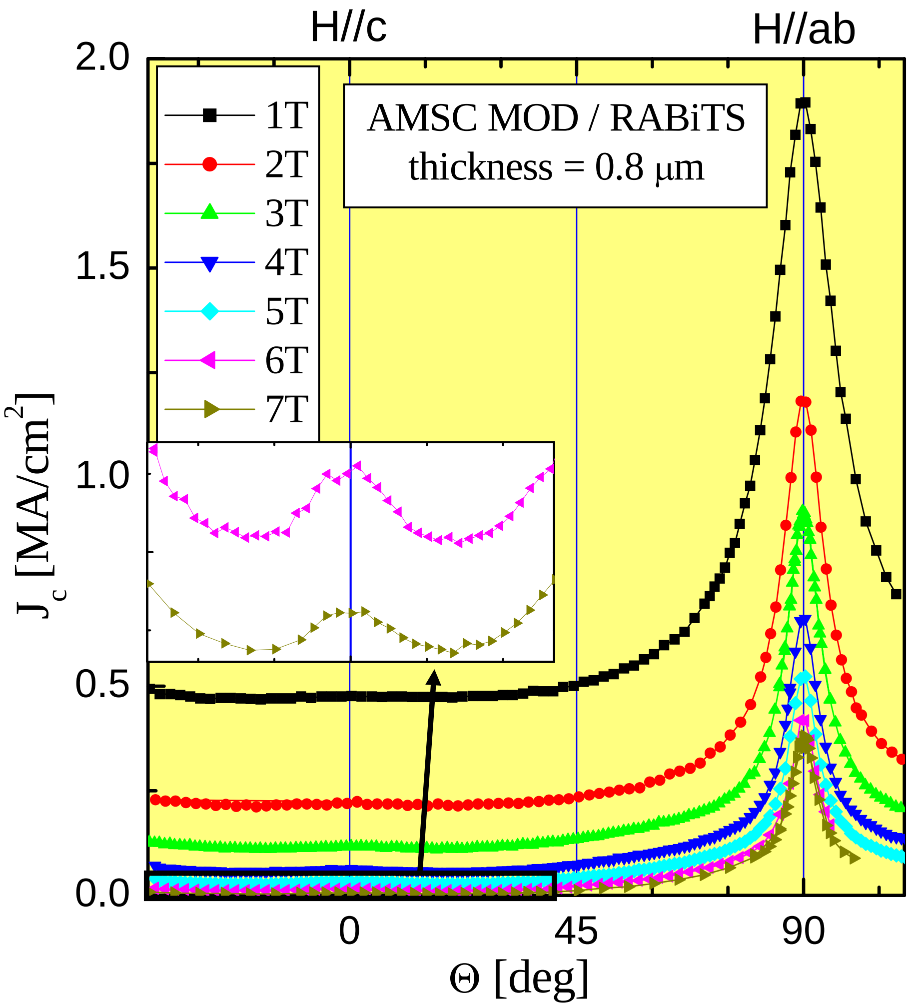
J_c^{sf} = 3.1 MA/cm²

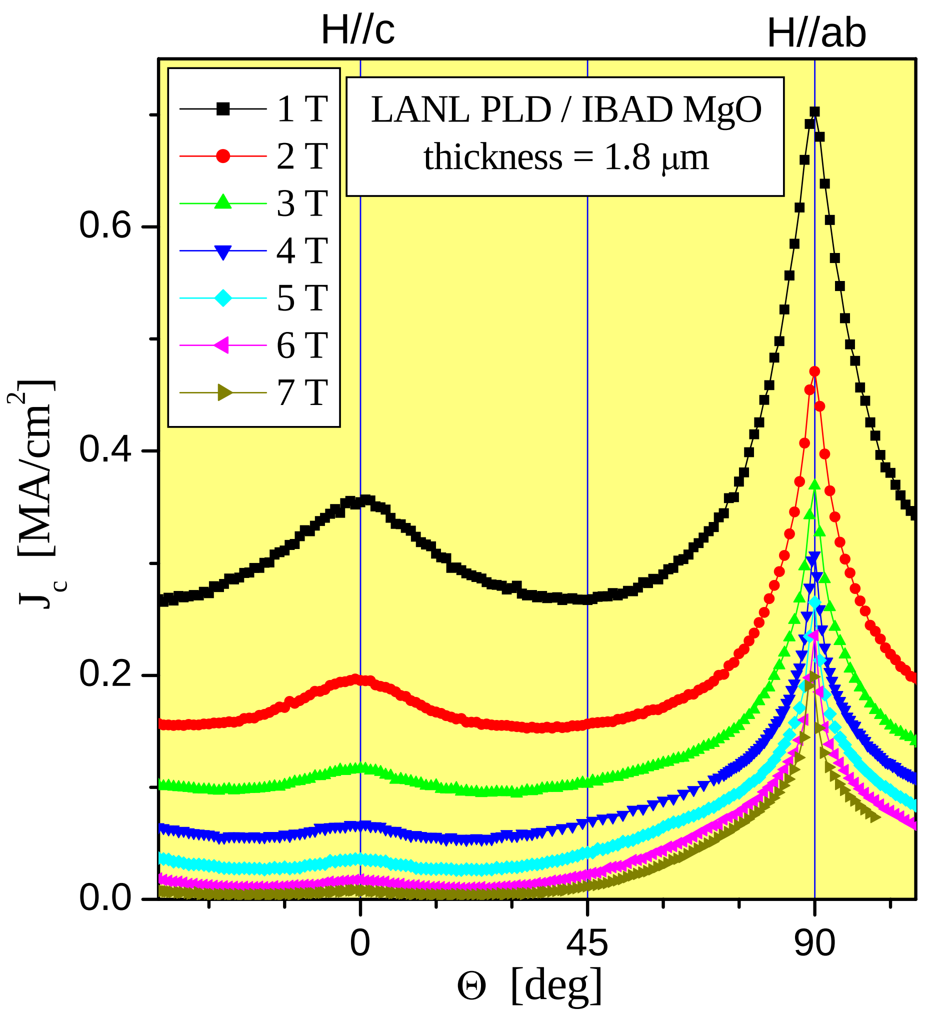
Pieces of long CC tapes



How does this compare with PLD films ?

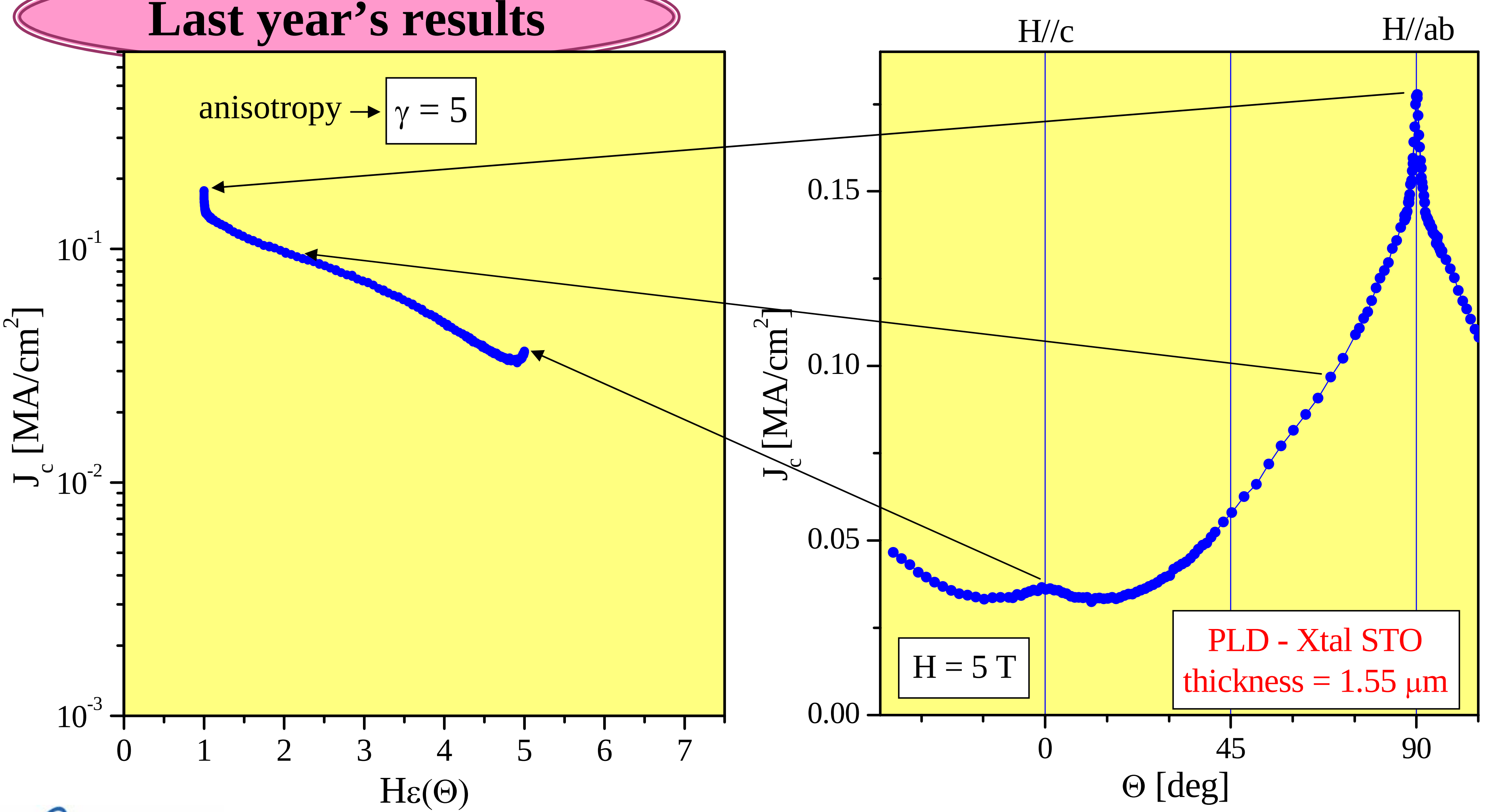
PLD: large c-axis peak, small ab-plane peak
MOD: small c-axis peak, large ab-plane peak





We had developed an anisotropic scaling method that allowed us to identify three pinning mechanisms in PLD films

Last year's results



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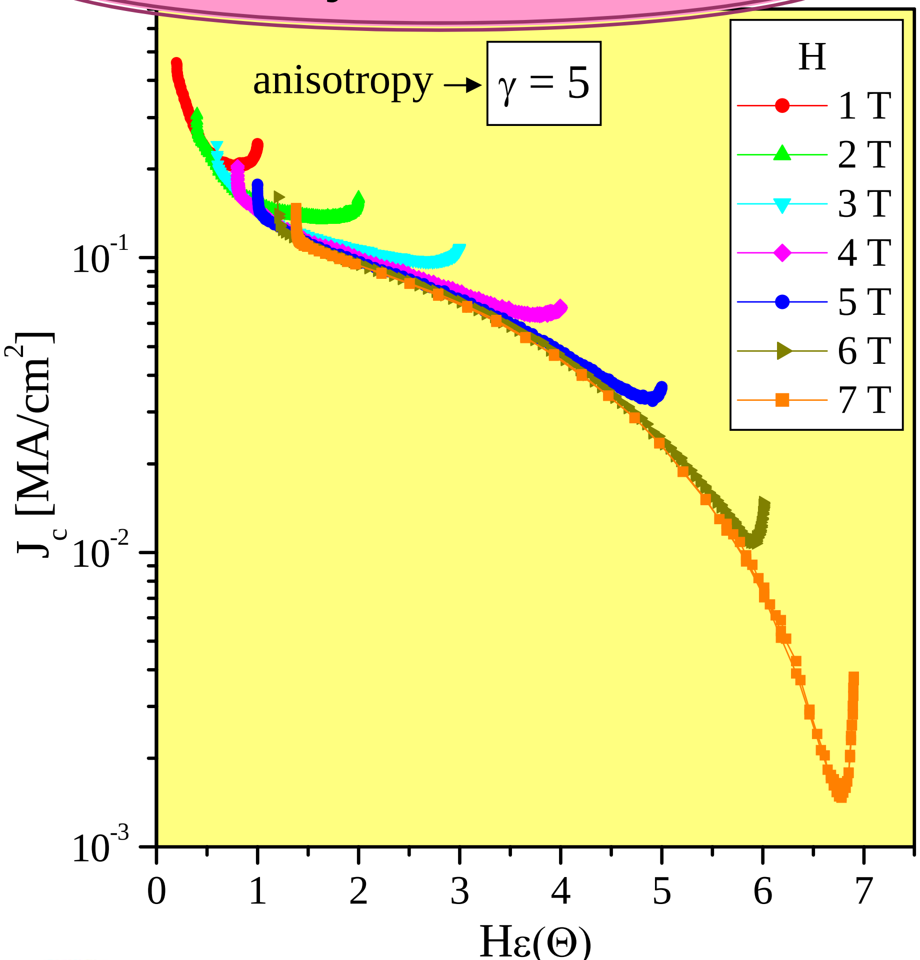
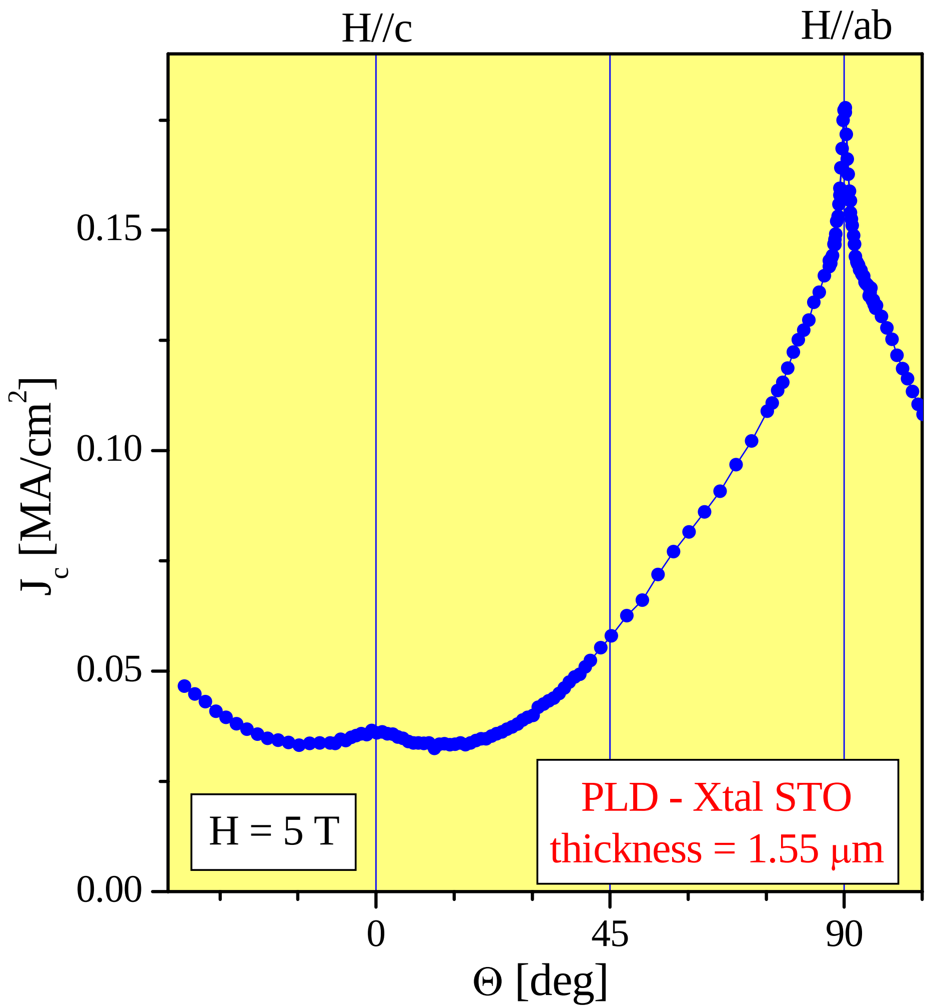
Last year's results





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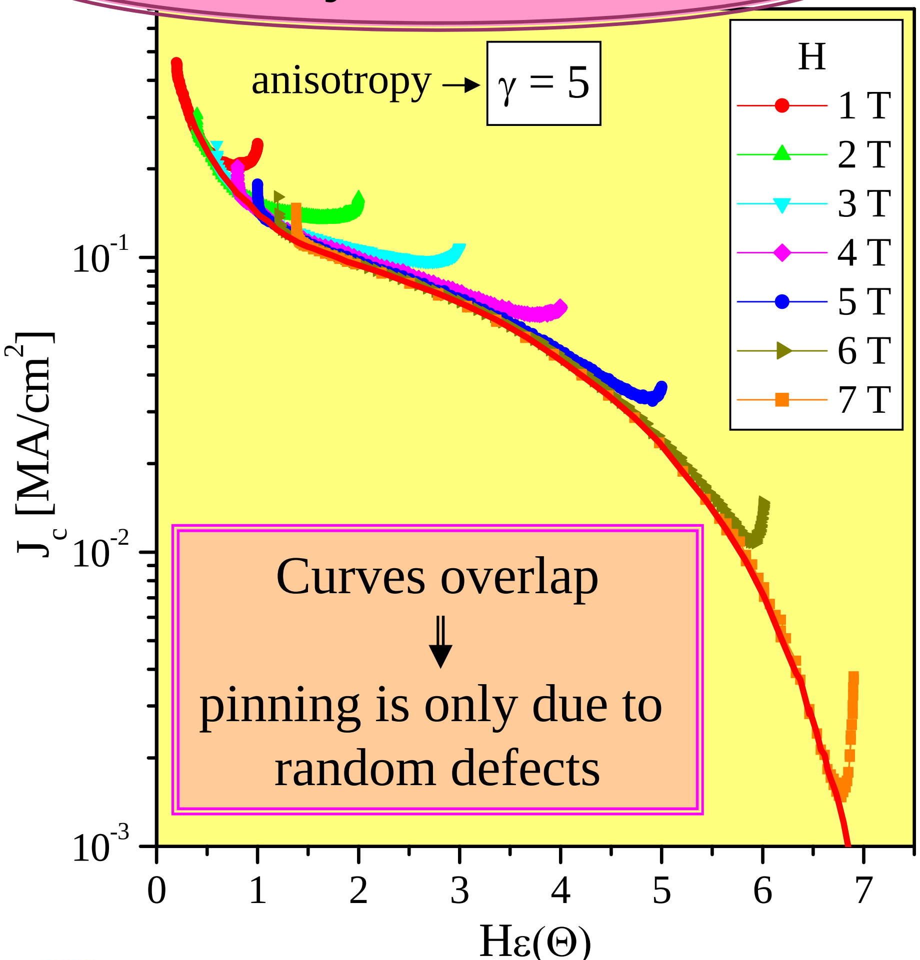

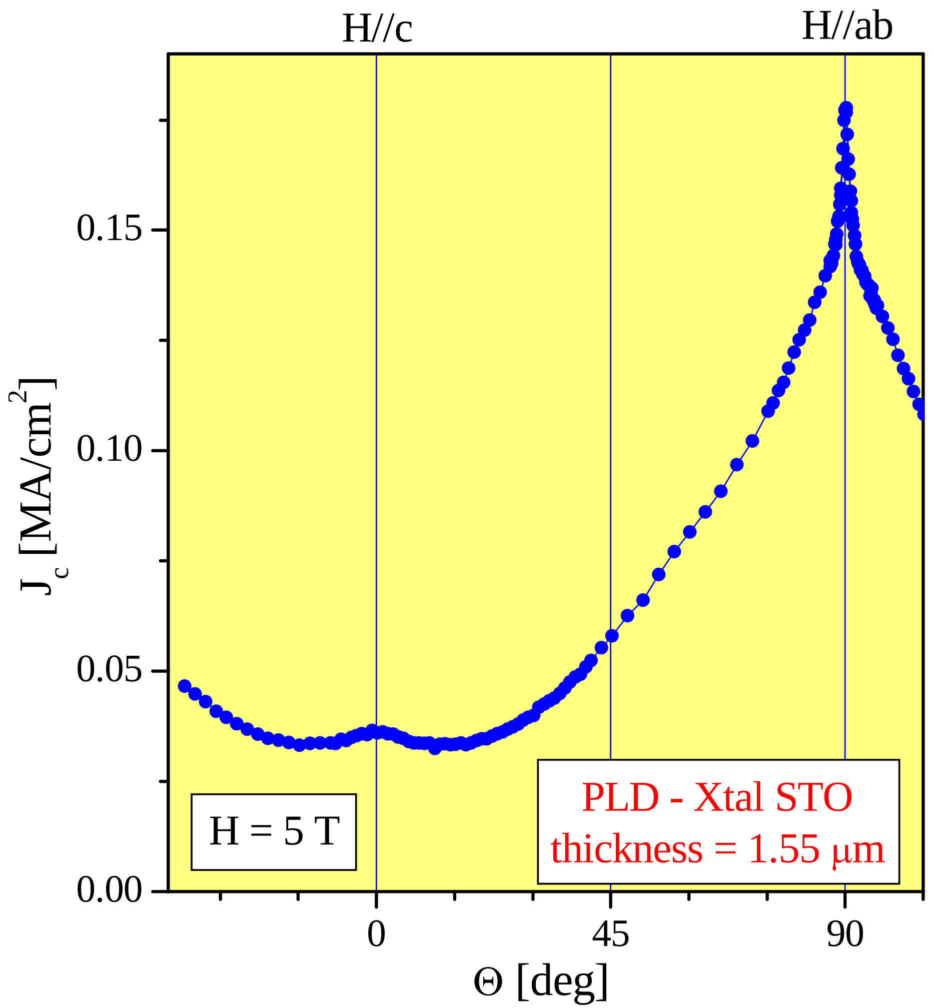

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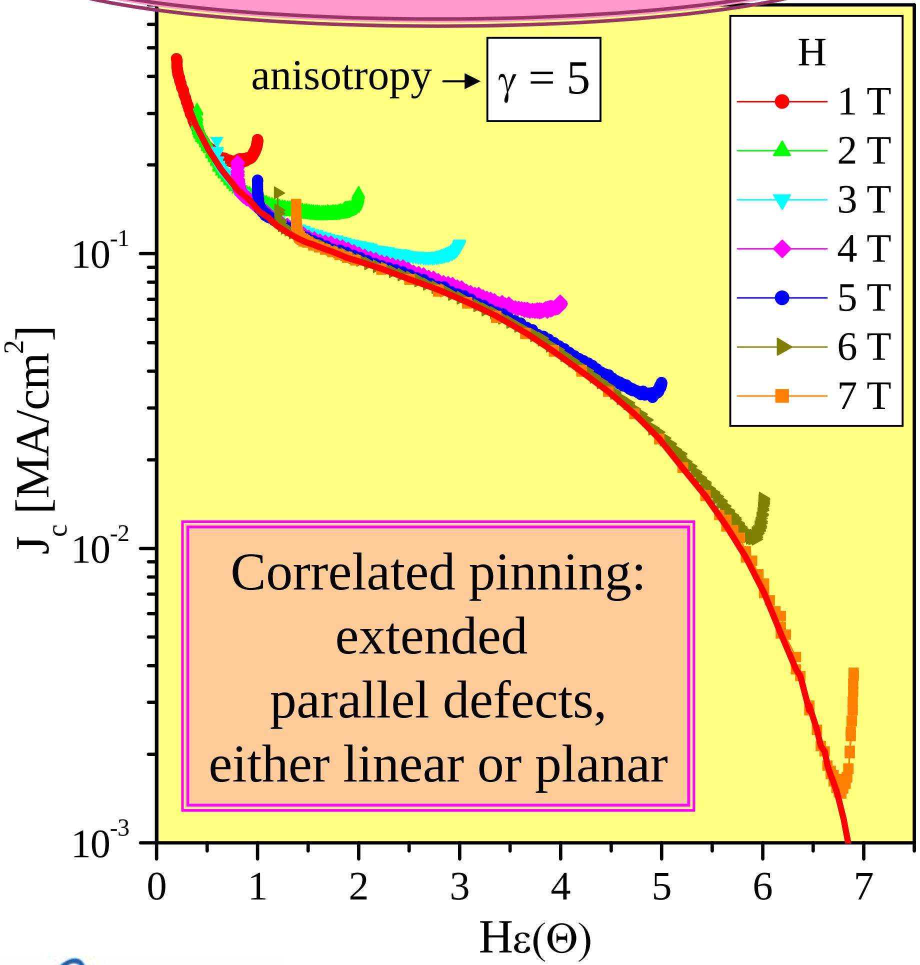
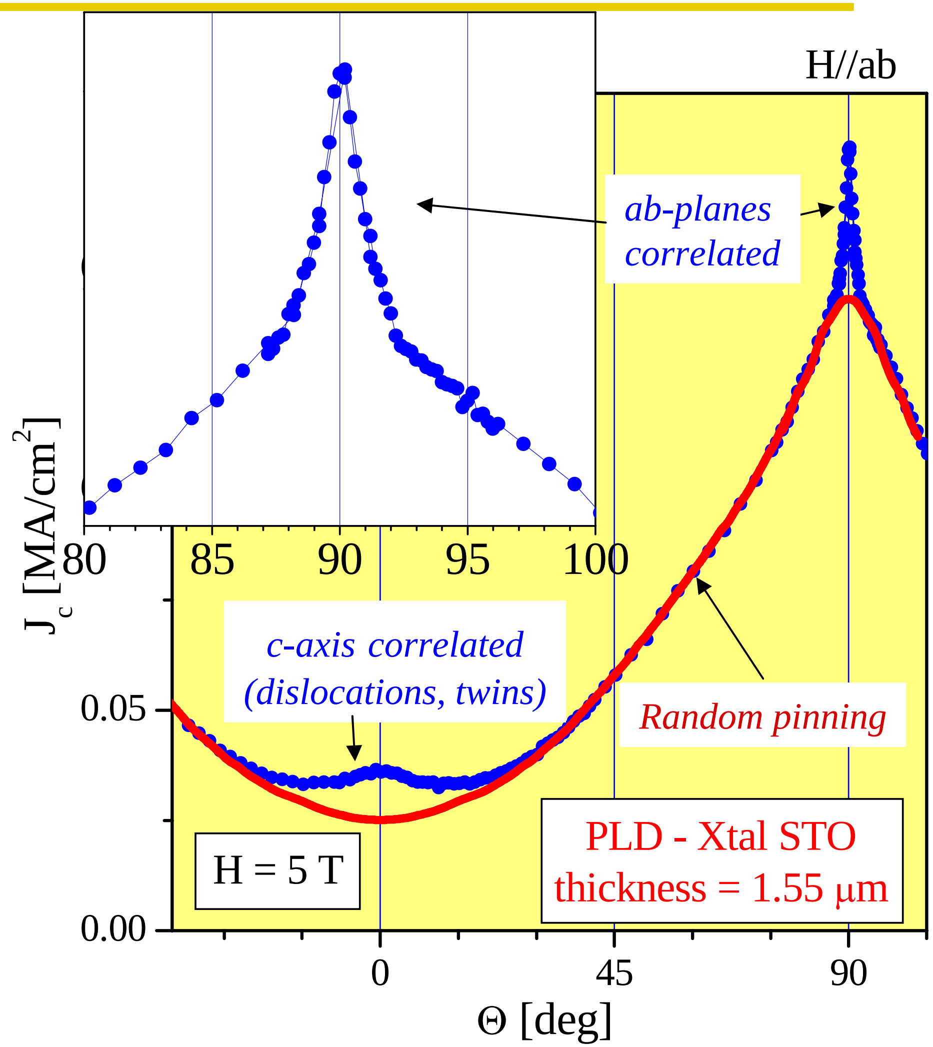
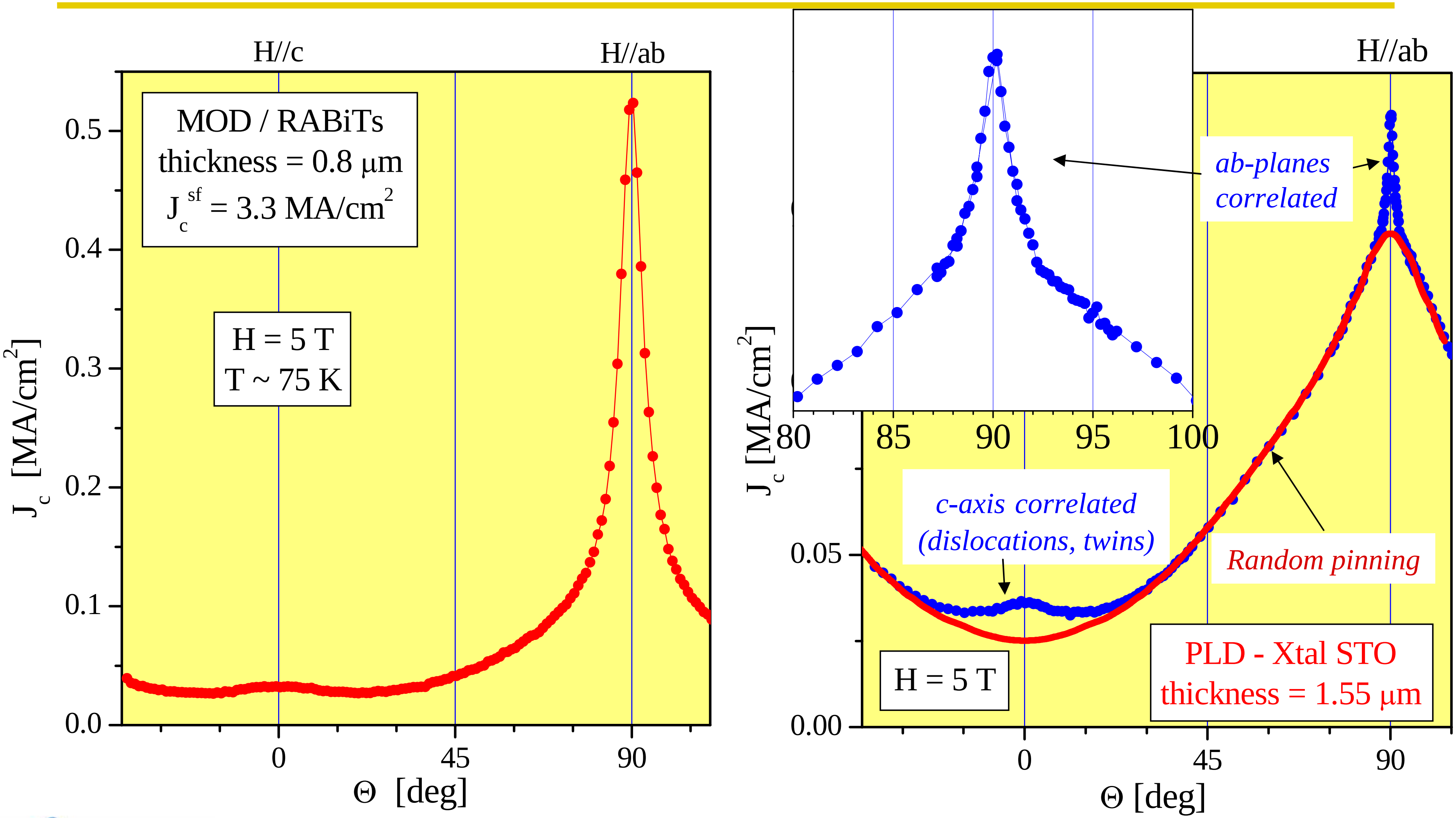
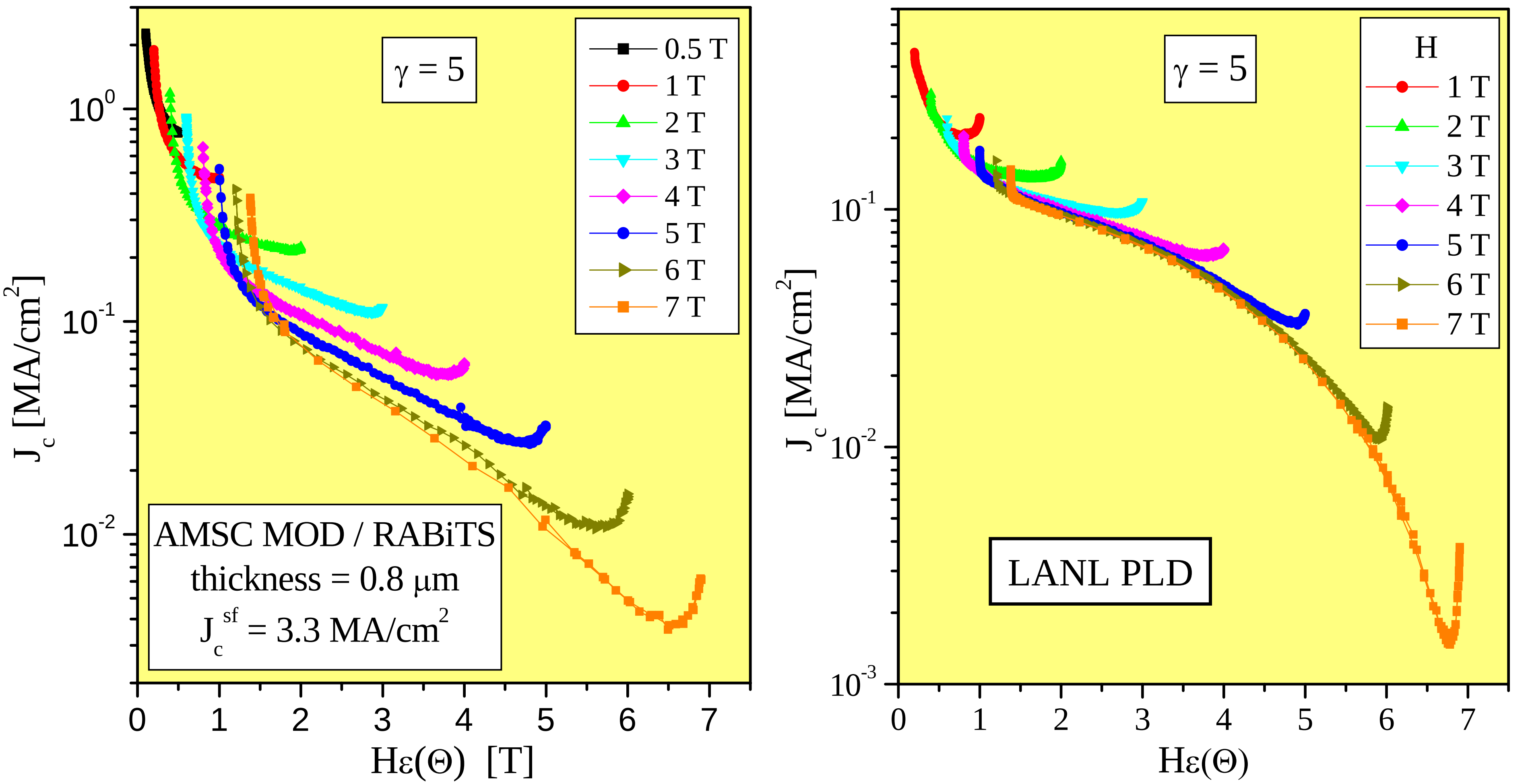




In MOD films there is no clear separation between random and ab-planes correlated pinning regimes

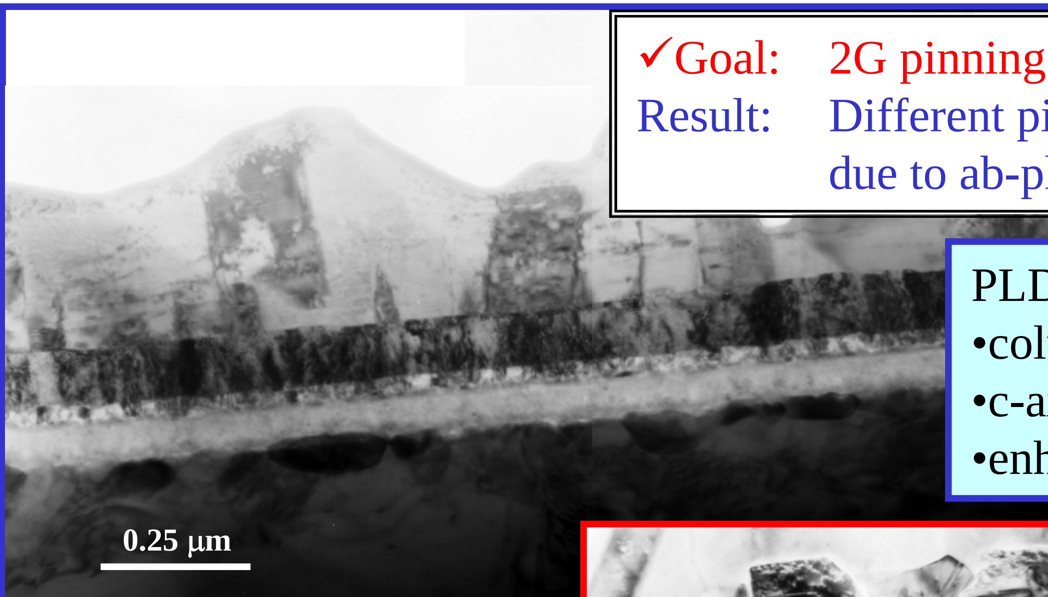


Anisotropic scaling does not work for MOD films, suggesting that correlated pinning is present for all orientations



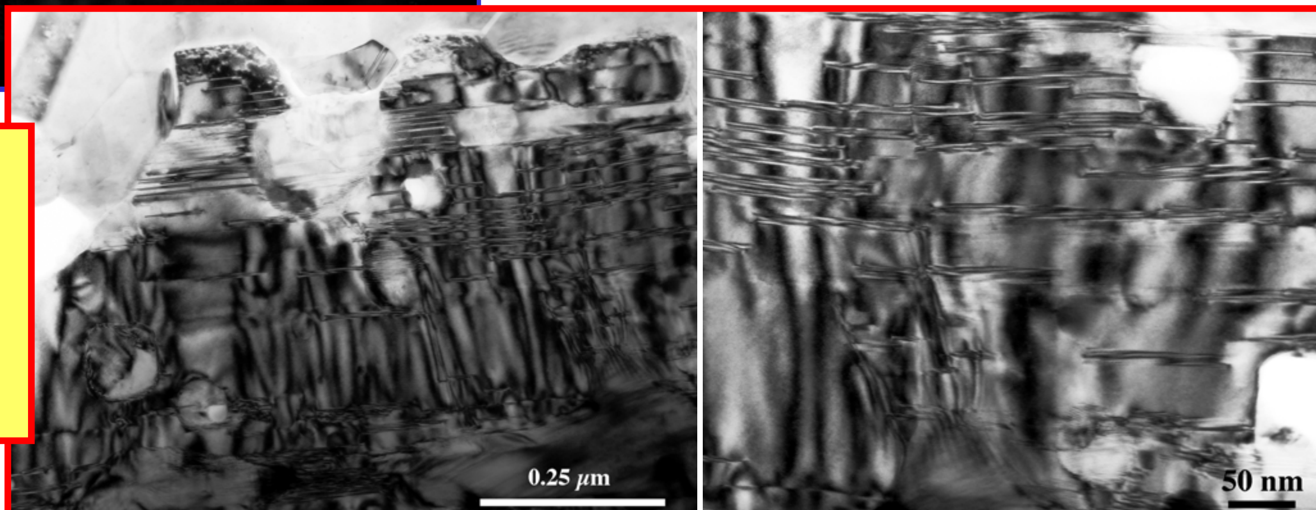
Pinning differences between MOD and PLD films clearly correlate with structural differences

✓Goal: 2G pinning - investigate pinning mechanisms in MOD
Result: Different pinning in MOD as compared to PLD due to ab-plane correlated structures seen by TEM.

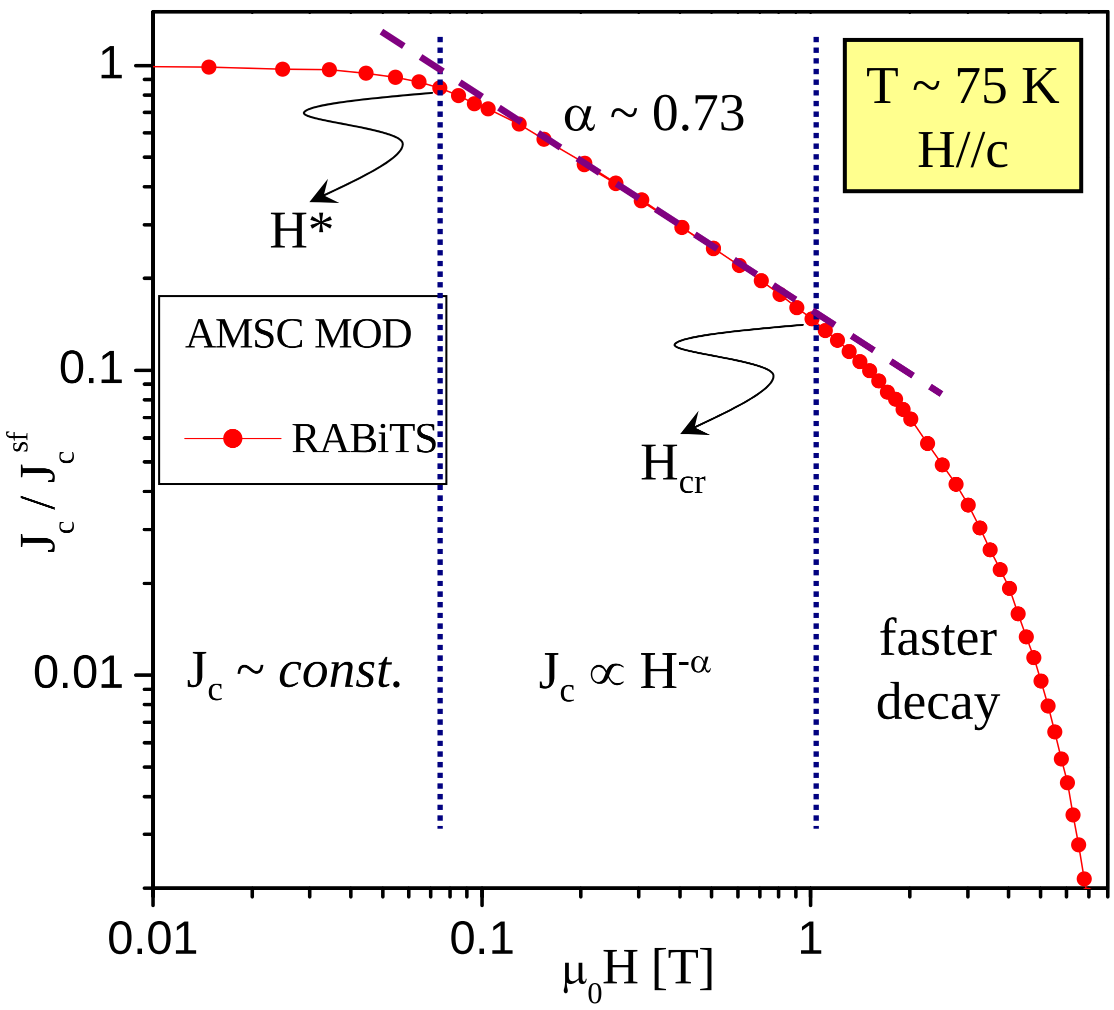


PLD:
- columnar growth
- c-axis correlated defects (dislocations)
- enhanced c-axis pinning

MOD:
- laminar growth
- ab-plane correlated defects (stacking faults)
- enhanced ab-plane pinning

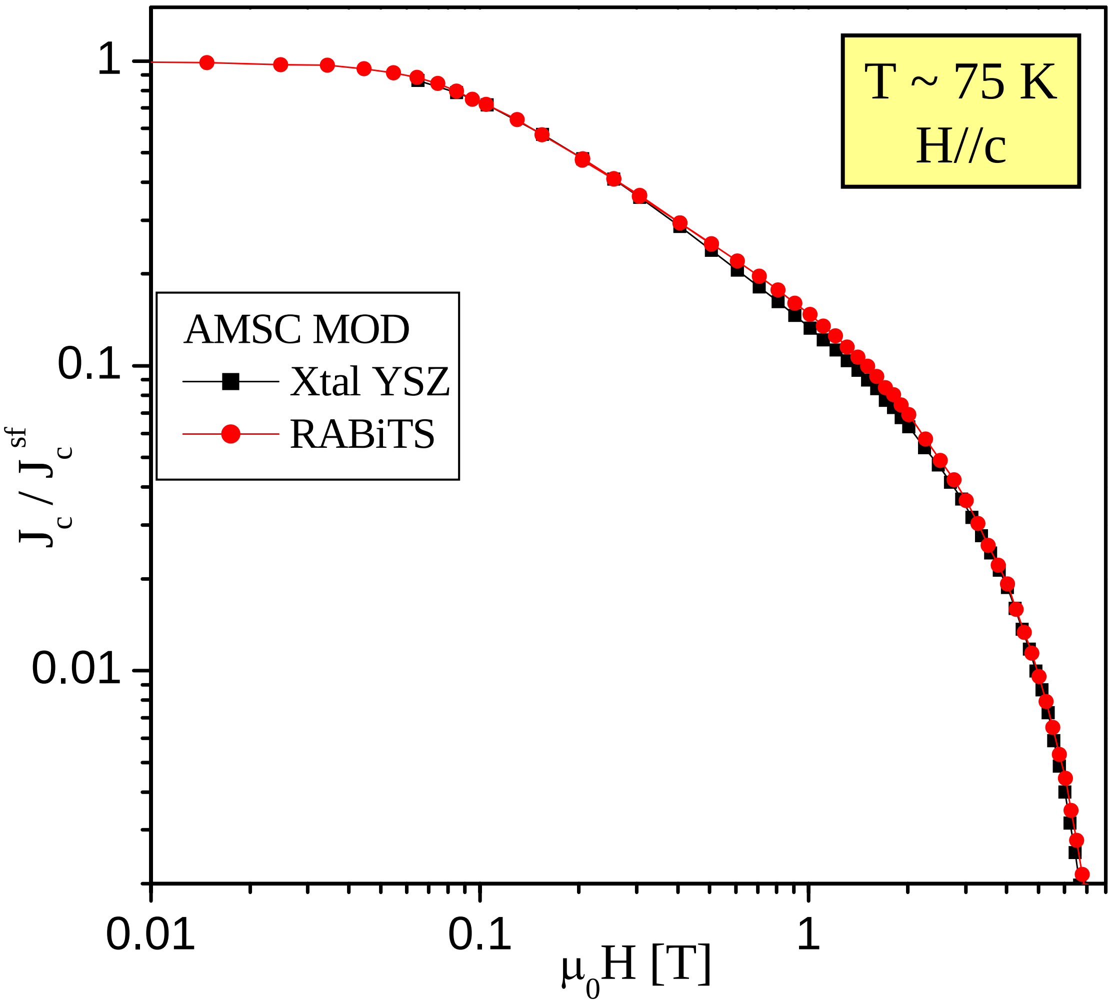


Field dependence of J_c for H//c: Three regimes



- Widely observed behavior
- H < H* ⇒ single vortex pinning
- H* ~ density of defects (B. Dam et al) (may be affected by self field effects)
- **$J_c \propto H^{-\alpha}$ ⇒ technologically relevant regime**
- **smaller α ⇒ better field dependence**

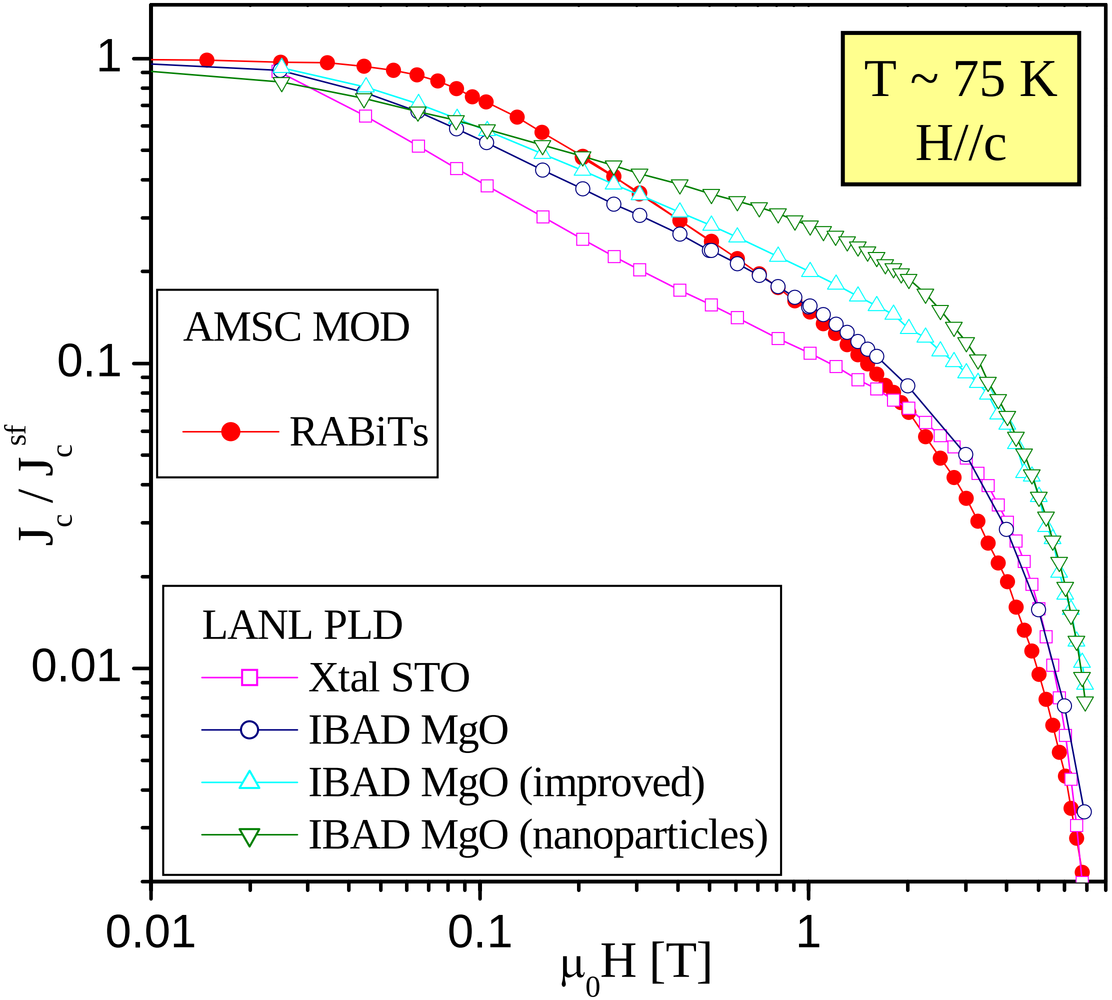
α has a repetitive, architecture-dependent value ⇒ useful process-characterization parameter



MOD

YBCO	Substrate	α
pure	Xtal YSZ	0.77±0.01
pure	RABiTs	0.70±0.03

α is smaller for PLD due to larger c-axis peak, and can be further reduced by nano-engineering of defects…



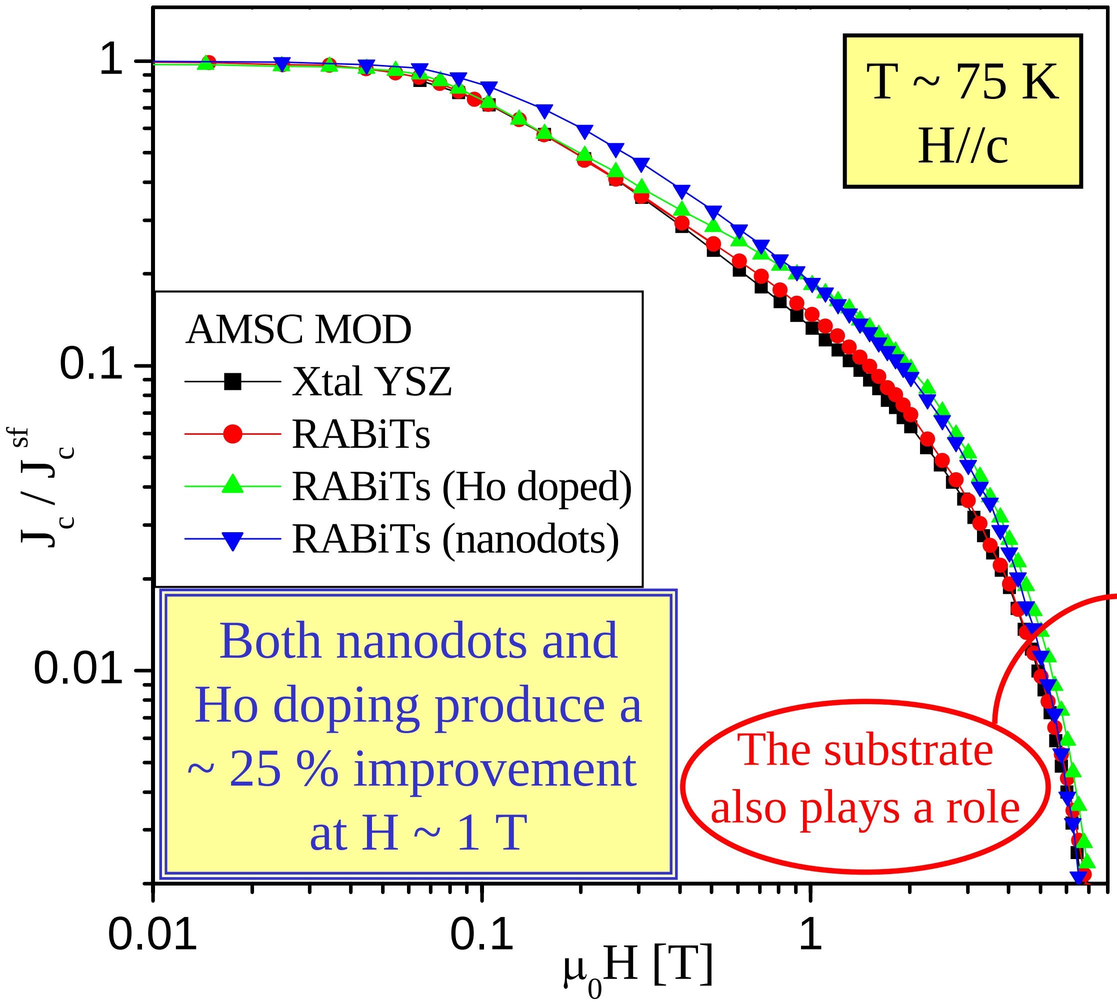
MOD

YBCO	Substrate	α
pure	Xtal YSZ	0.77±0.01
pure	RABiTs	0.70±0.03

PLD

YBCO	Substrate	α
pure	Xtal STO	0.57
pure	IBAD MgO	0.53
improved	IBAD MgO	0.48
BZO nanoparticles	IBAD MgO	0.33

…but α in MOD can also be reduced by defects' nano-engineering



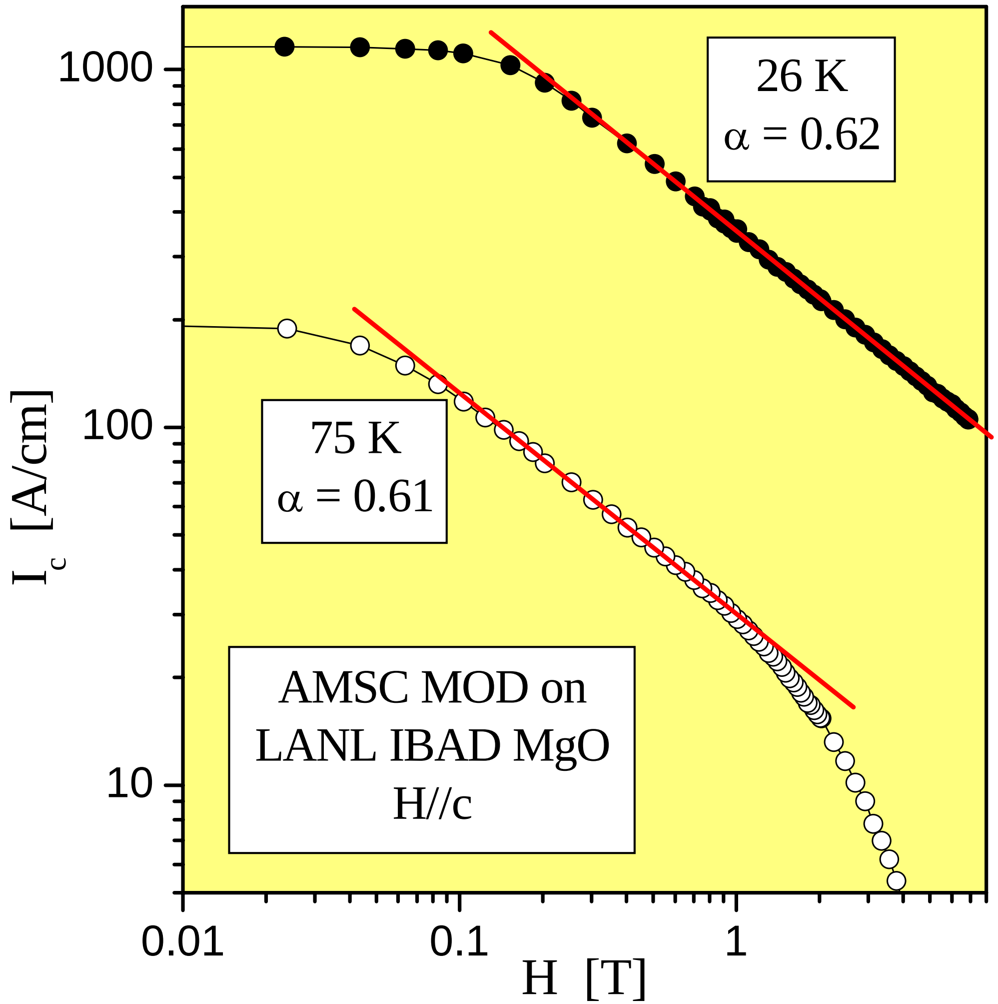
MOD

YBCO	Substrate	α
pure	Xtal YSZ	0.77±0.01
pure	RABiTs	0.70±0.03
+ nanodots	RABiTs	0.67
20% Ho	RABiTs	0.60
pure	IBAD MgO	0.61

PLD

YBCO	Substrate	α
pure	Xtal STO	0.57
pure	IBAD MgO	0.53
improved	IBAD MgO	0.48
BZO nanoparticles	IBAD MgO	0.33

α is temperature independent
H_{cr} increases as T decreases

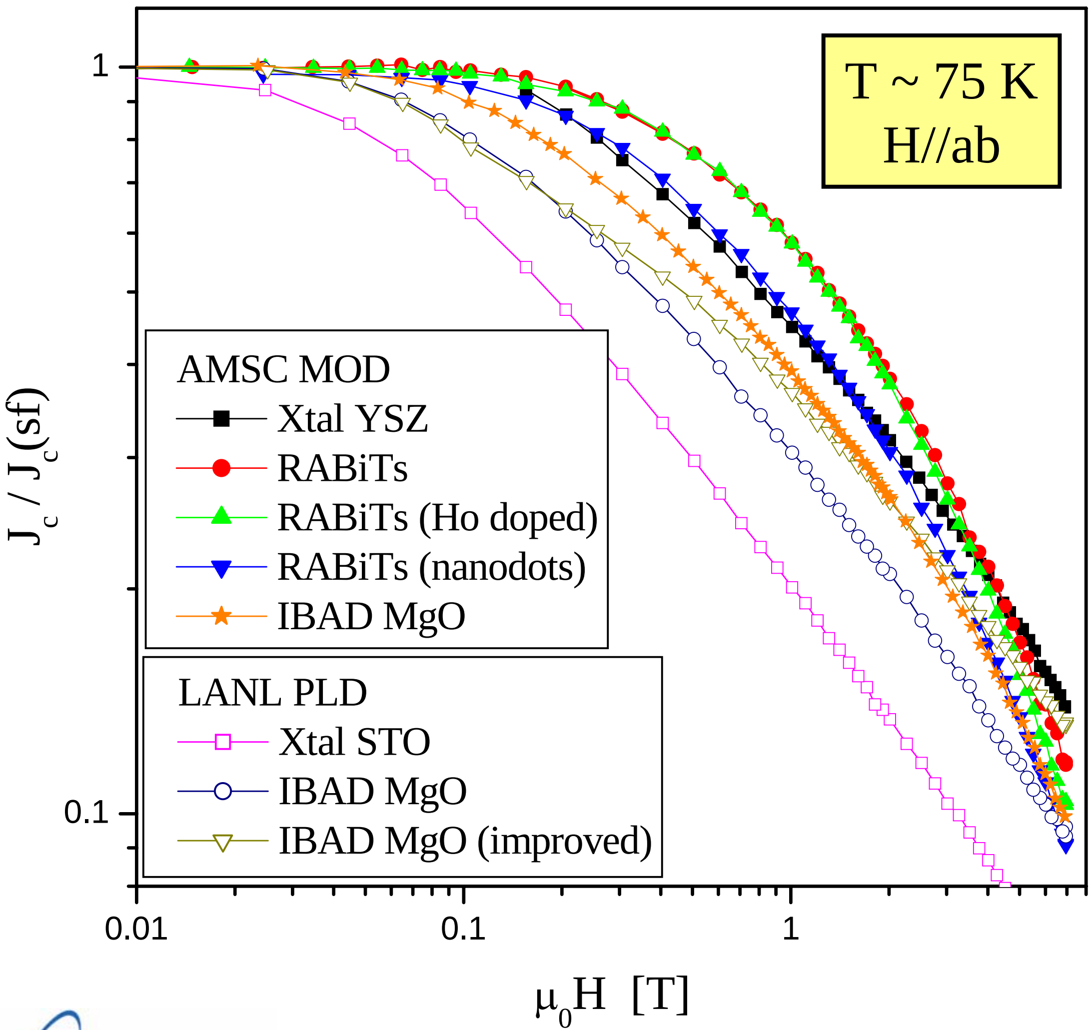


estimate:

$H_{cr}(T) \sim 0.15 * H_{irr}(T)$

Below T ~ 40 K,
for H//c
we should only care
about the $J_c \propto H^{-\alpha}$ regime

Field dependence of J_c for H//ab: better in MOD than in PLD due to larger density of correlated defects along ab-planes

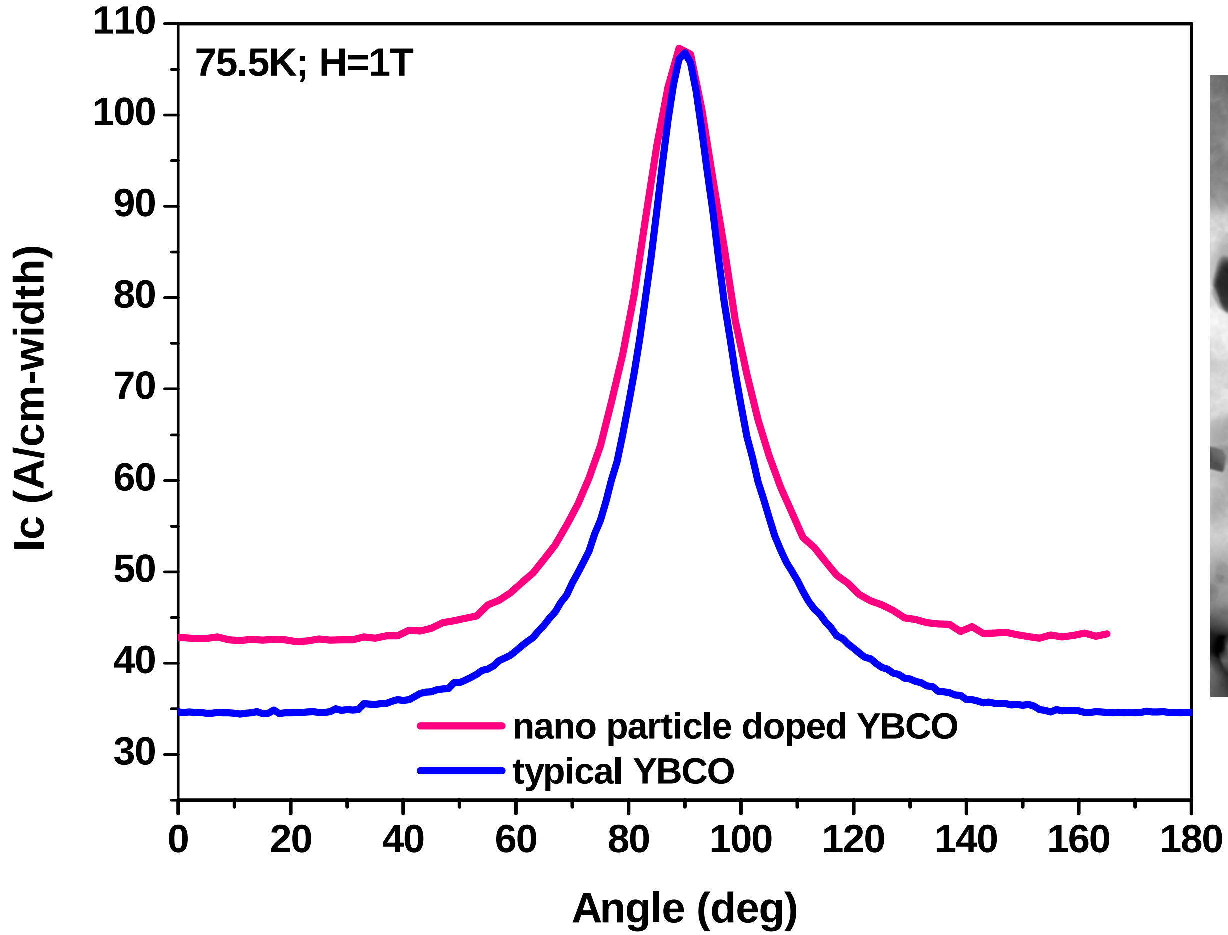


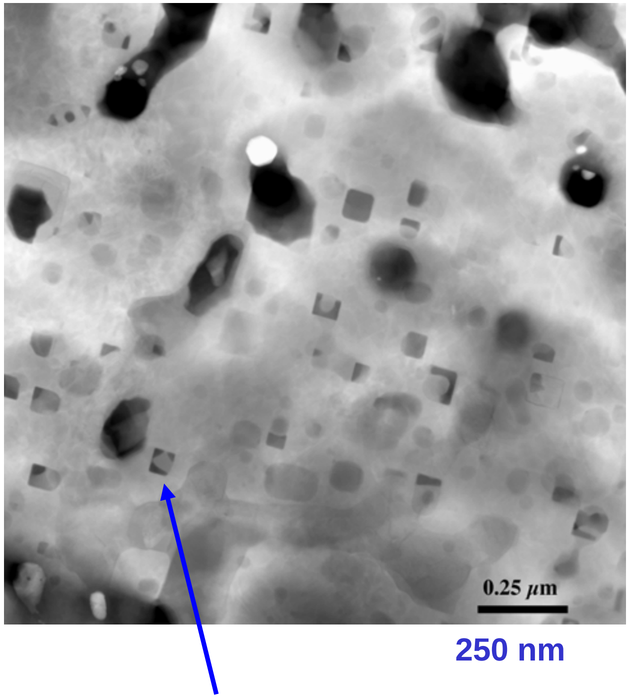
- H < H* ⇒ single vortex pinning
- larger H* as compared to H//c
- no obvious $J_c \propto H^{-\alpha}$ regime

- Extra defects introduced by Ho doping or nanodots have small effect on J_c for H//ab

- MOD on IBAD MgO has an intermediate behavior

Angular Dependence at 75K: With/Without Nanodot Addition

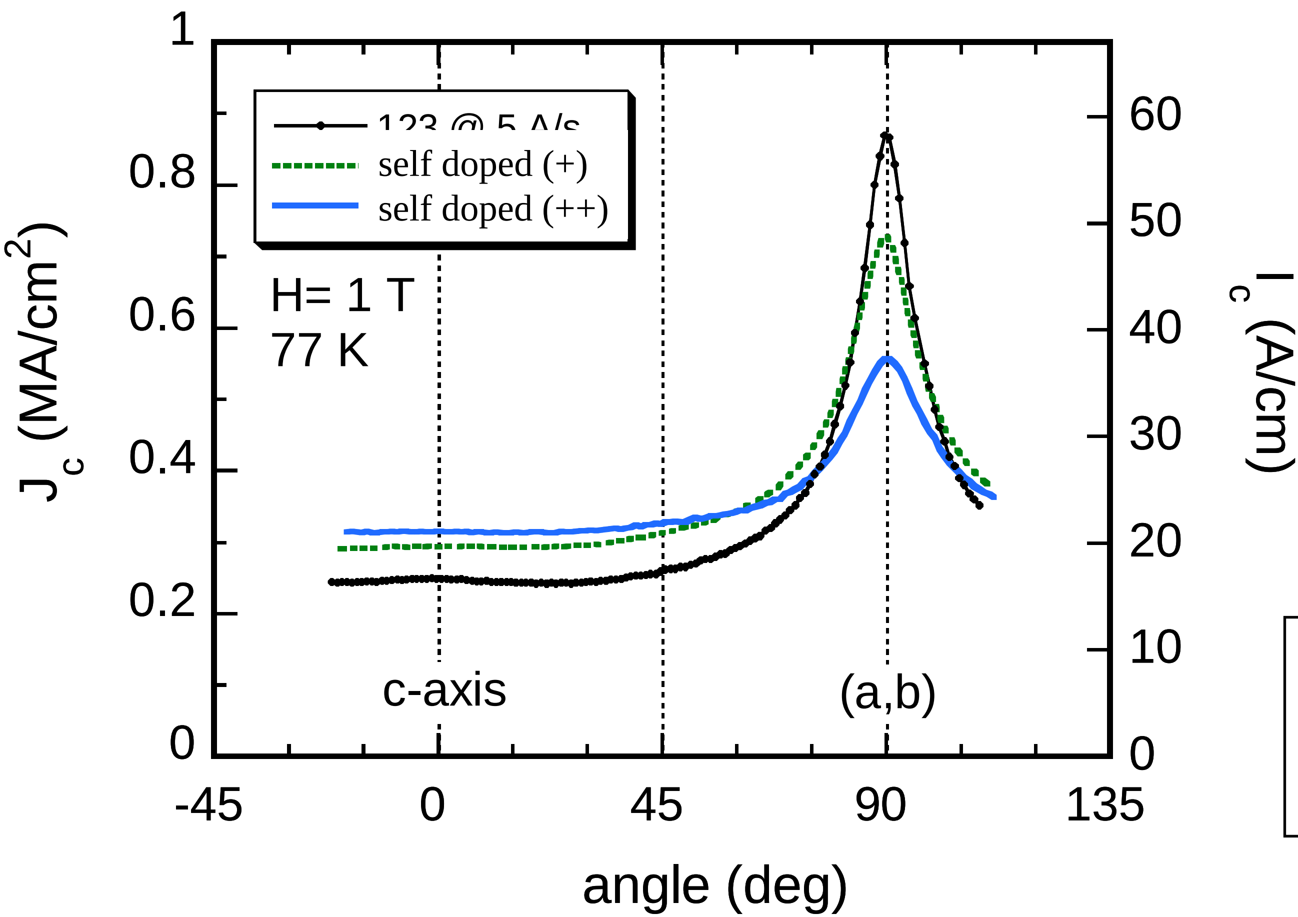




250 nm

Nano-particle doping improves performance ~25% in 1T perpendicular field

Self-doping reduces the J_c anisotropy



Studies performed by R. Feenstra, ORNL

- J_c || (a,b) is reduced
- J_c || c is enhanced
- J_c^{max} / J_c^{min}: > 4 → < 2

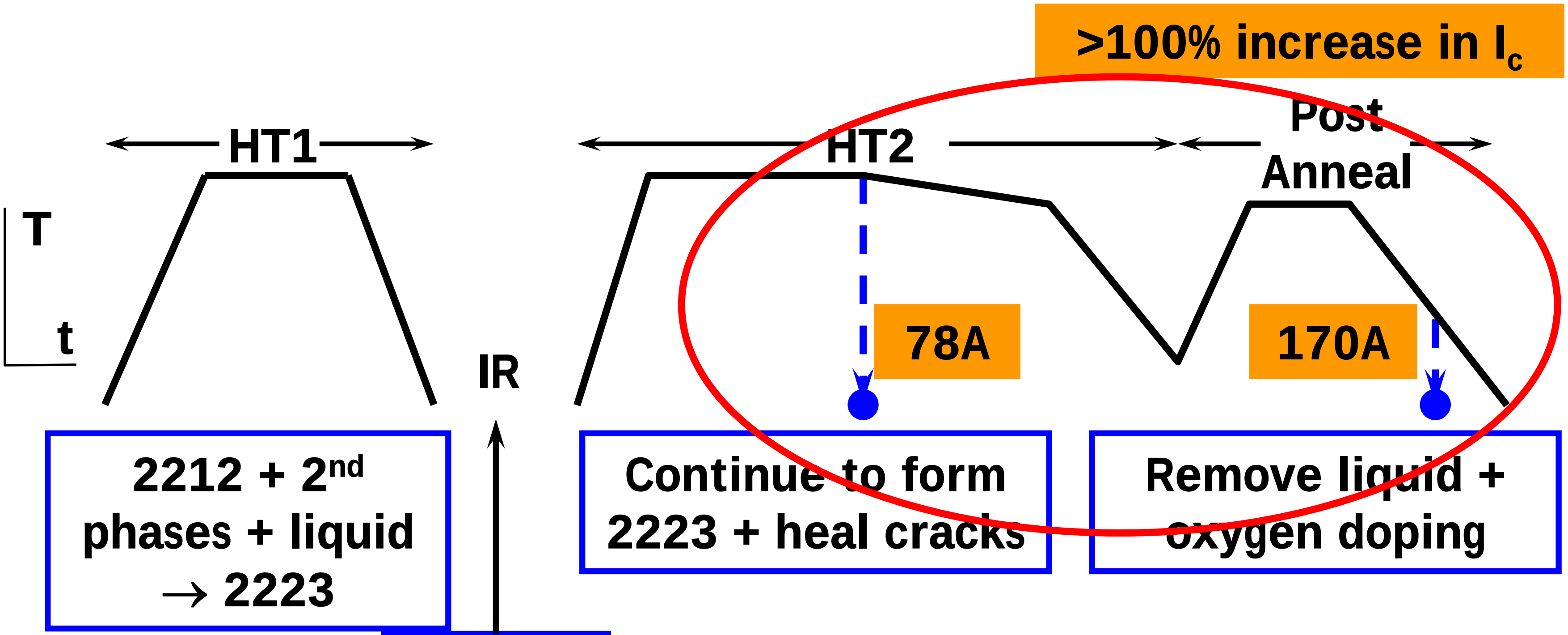
Summary

- Laminar growth associated to the MOD method in AMSC CC results in large density of planar defects parallel to ab-planes, which dominates pinning in a wide angular range. Clear correlation between flux pinning and structural properties as revealed by TEM.

- Both introduction of nanoparticles and Ho-doping produce pinning improvement, with ~ 25% J_c enhancement at H=1T for H//c, a reduction of field decay parameter α to ~ 0.6, and reduced anisotropy.

- Both self-doping and fast conversion also reduce the J_c anisotropy in AMSC and ORNL ex-situ films.

1G BSCCO thermomechanical processing is complicated



PhD theses Y. Yuan and S. Liao

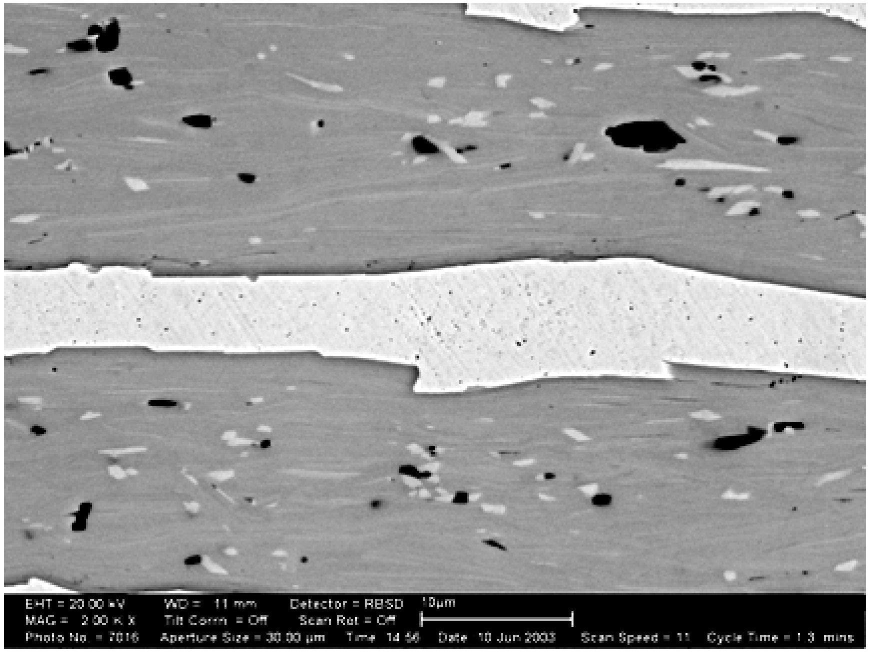
Approach to increase J_c in BSCCO

- Identify, understand, and eliminate current limiting mechanisms (CLM)
  - Pores and cracks
  - Residual 2212
  - Processes in Post Anneal that affect:
    - Flux pinning
    - Connectivity
- Hellstrom - Global properties
- Larbalestier – Local properties

CLM – Pores and cracks

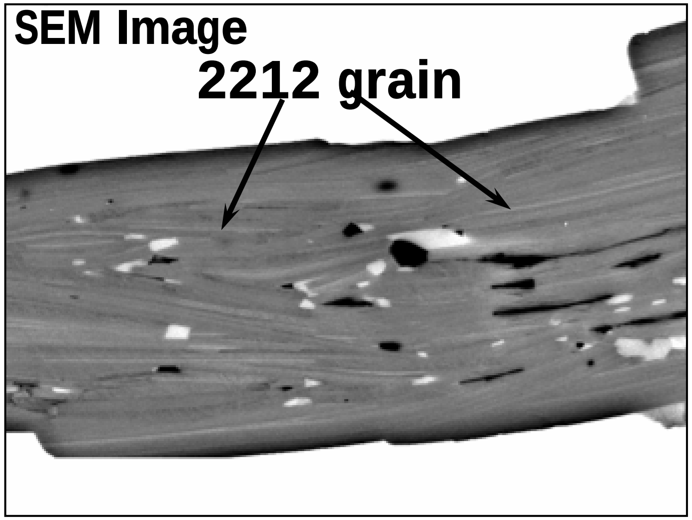
- **Overpressure (OP) processing closes pores and heals cracks**
- **202 A - record $I_c \Rightarrow$ 470 A/cm width**
- **Used as a tool to densify samples**
- **OP studies on hold this year**
- **Sumitomo Electric industrializing OP processing**

J_c (0.1T, 77K) = 30.2 kA/cm^2

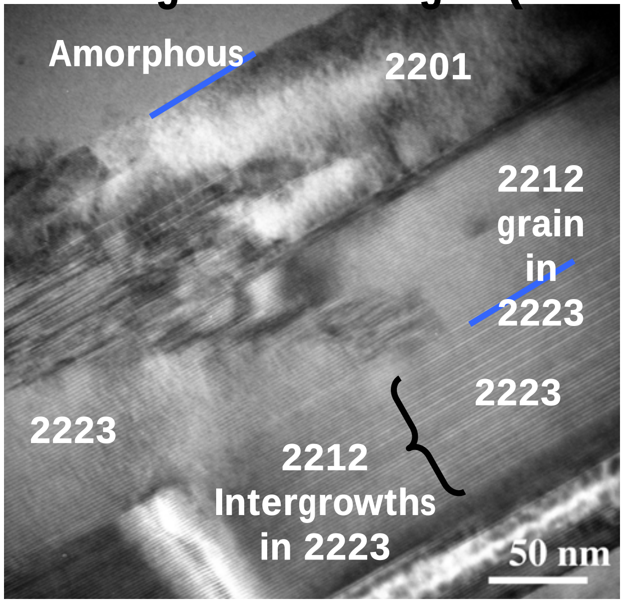


CLM – 2212

- ‘03 identified 2212 as a major CLM
  - Decreasing 2212 SQUID index increases J_c
- Changing heat treatment does not eliminate 2212 with current powder
- Varying “2223” composition to reduce 2212 put on hold
- Refined 2212 SQUID magnetization analysis to measure T_c of 2212

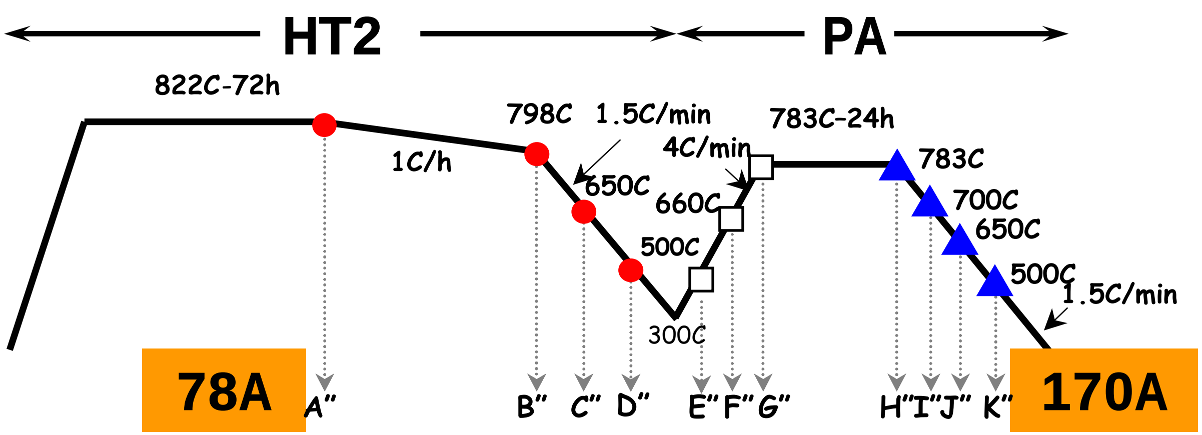


TEM image – Holesinger (LANL)



CLM – During Post Annealing (PA)

Through-process quench samples



- Driving 2212 => 2223
- Remove liquid
- Re-generate liquid
- Crystallize liquid
- Enhanced doping of 2212/2223

Hypothesis

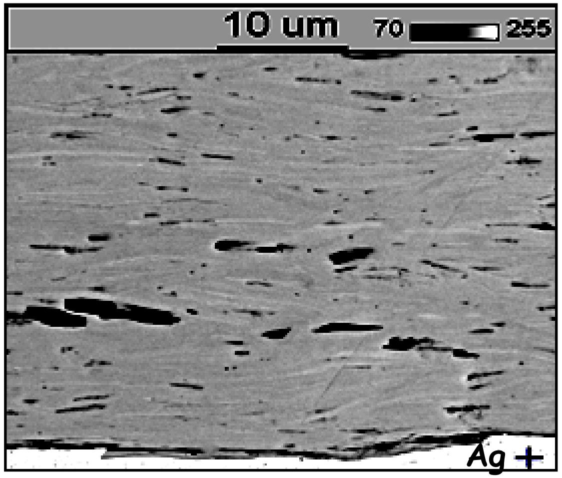
- 1st direct correlation of processing, microstructure, and electromagnetic properties
- Yuan and Liao PhD theses

>100% increase in I_c

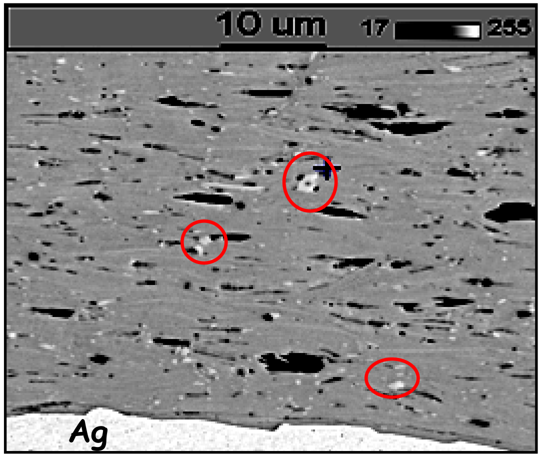
Investigate CLMs in PA related to:
- **Connectivity**
- **Flux pinning**

Hypothesis: liquid affects connectivity
Observation: 3221 develops from liquid during PA

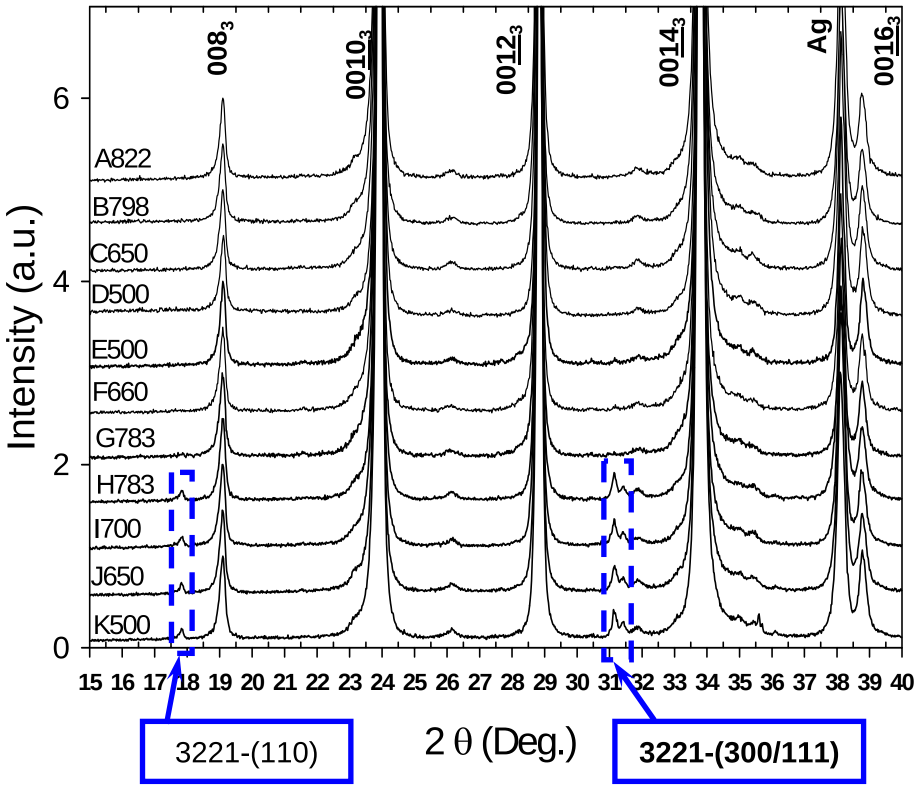
Before PA

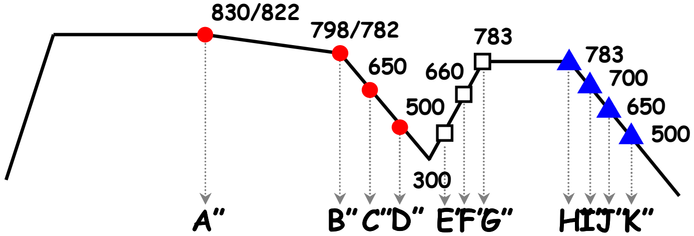


3221 develops during PA



XRD shows when 3221 develops in PA

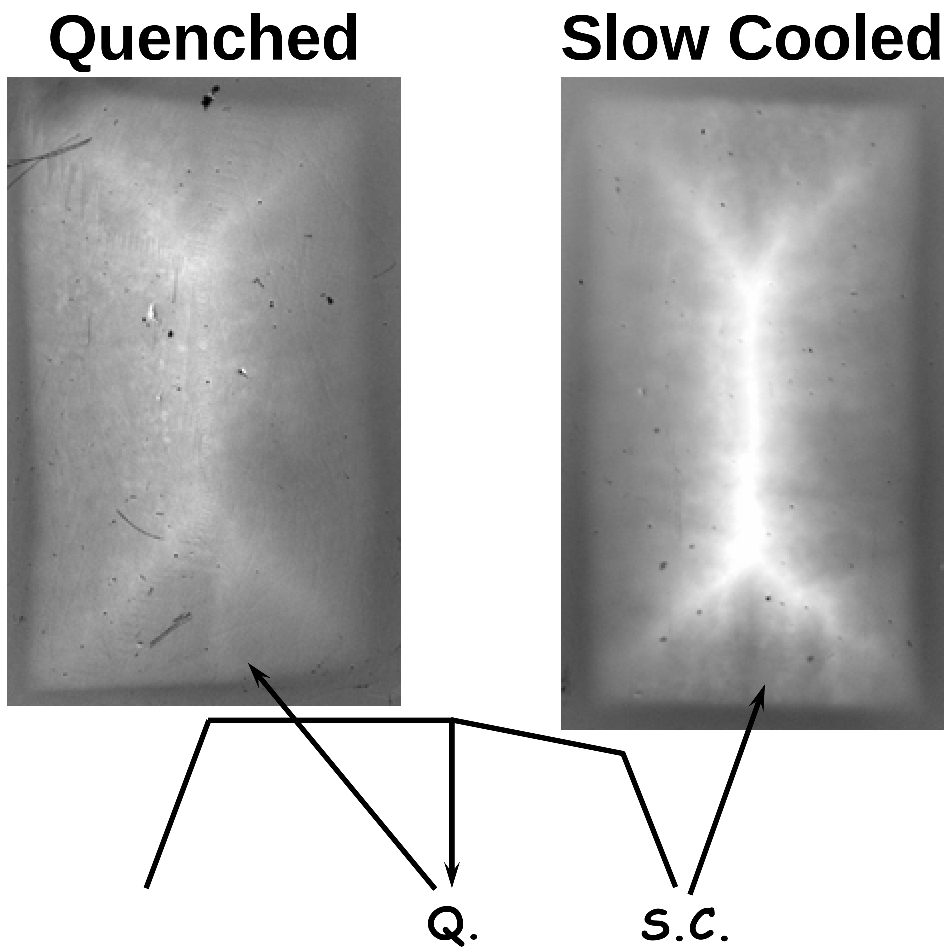




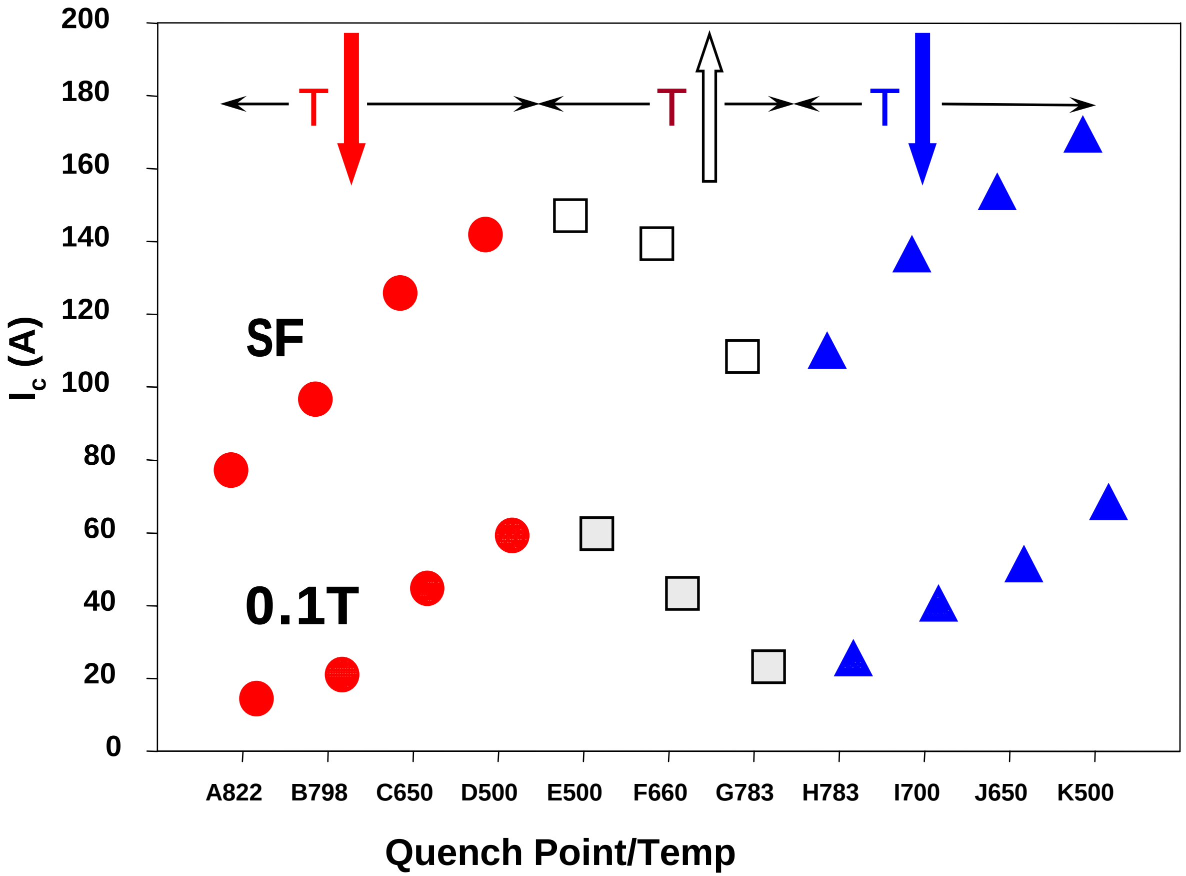
MO imaging shows no cracks in quenched samples

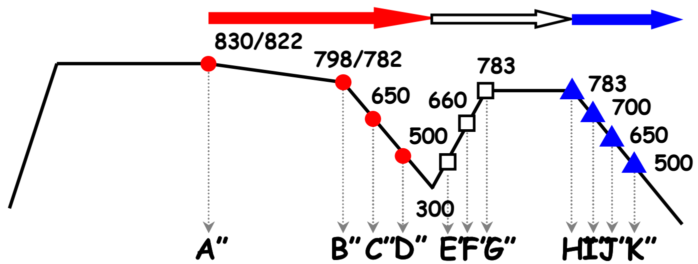
Magneto-optical image

T=11K, FC in H=1200 Oe



I_c varies with quenching temperature

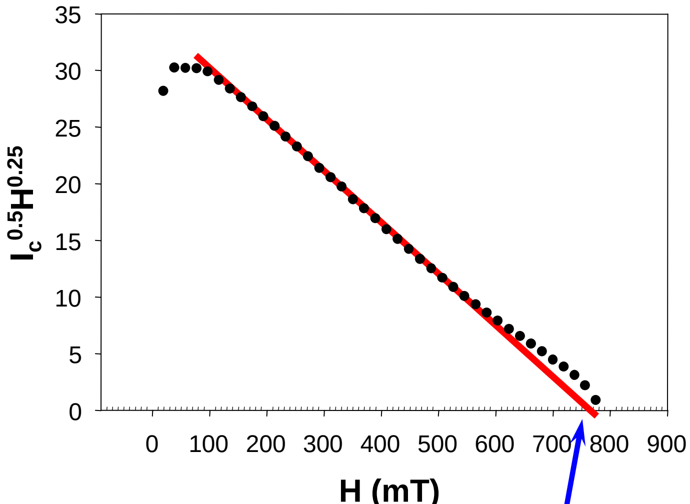




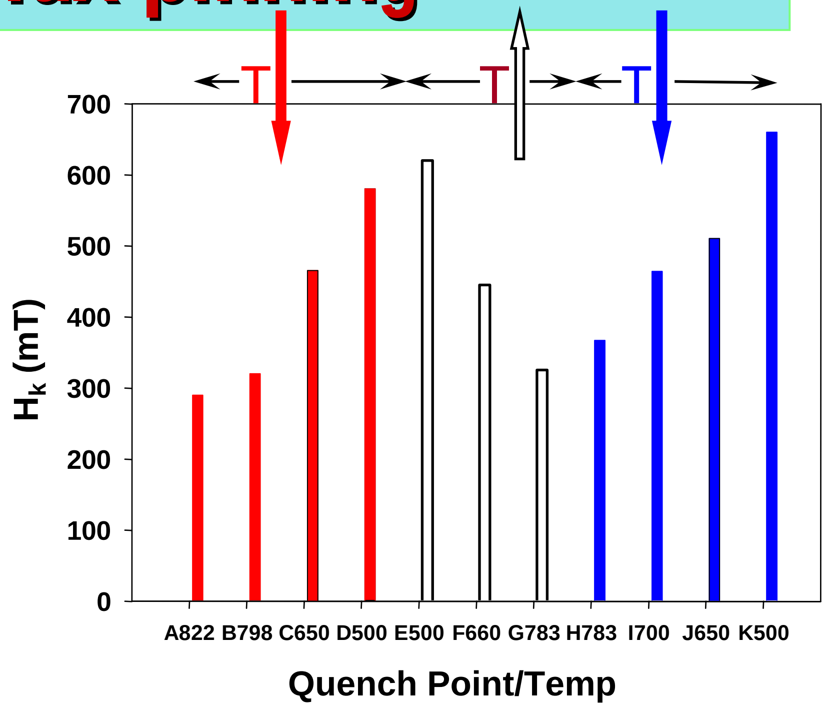
H_K - Kramer irreversibility field – is a measure of flux pinning

Definition and determination of H_K

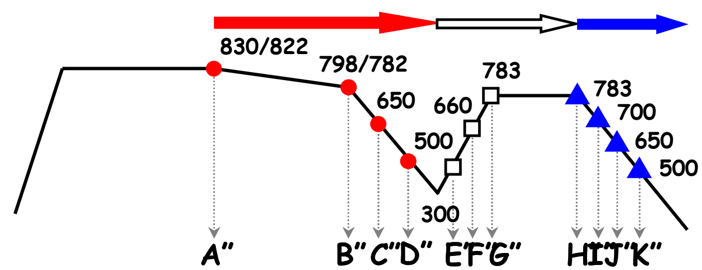
$I_c^{0.5} H^{0.25}$ = constant x (H_K- H)
Kramer, JAP 44, 1360 (1973)



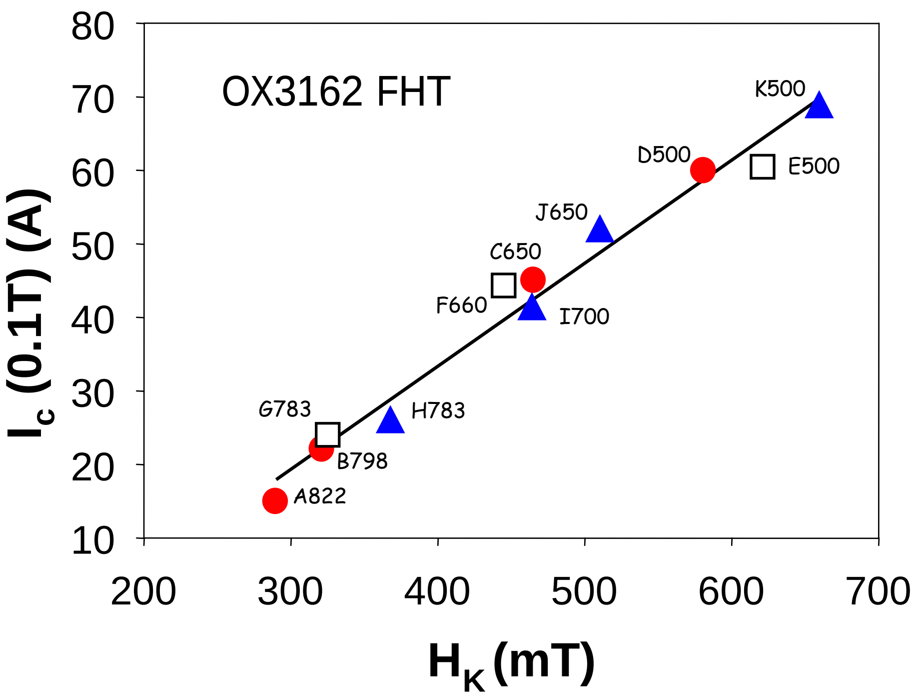
H_K =765 mT

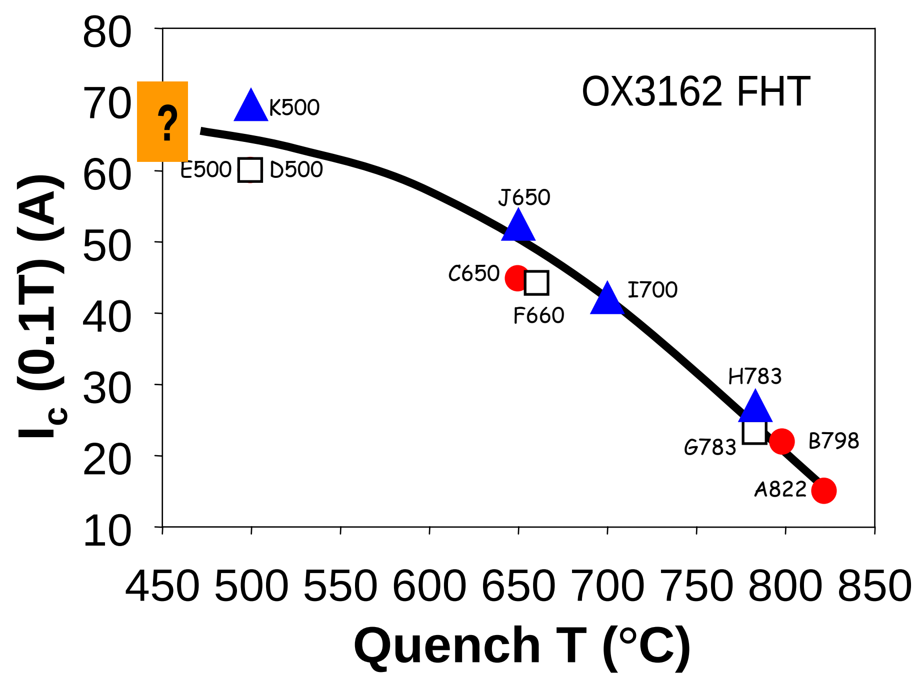


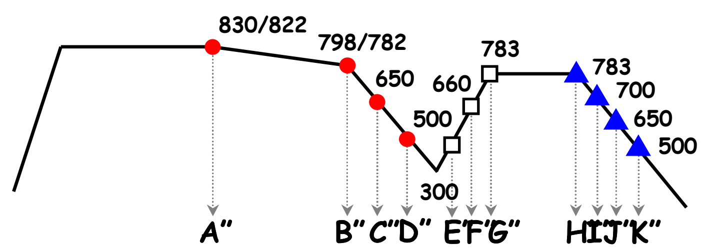
OX3162 FHT - 77K



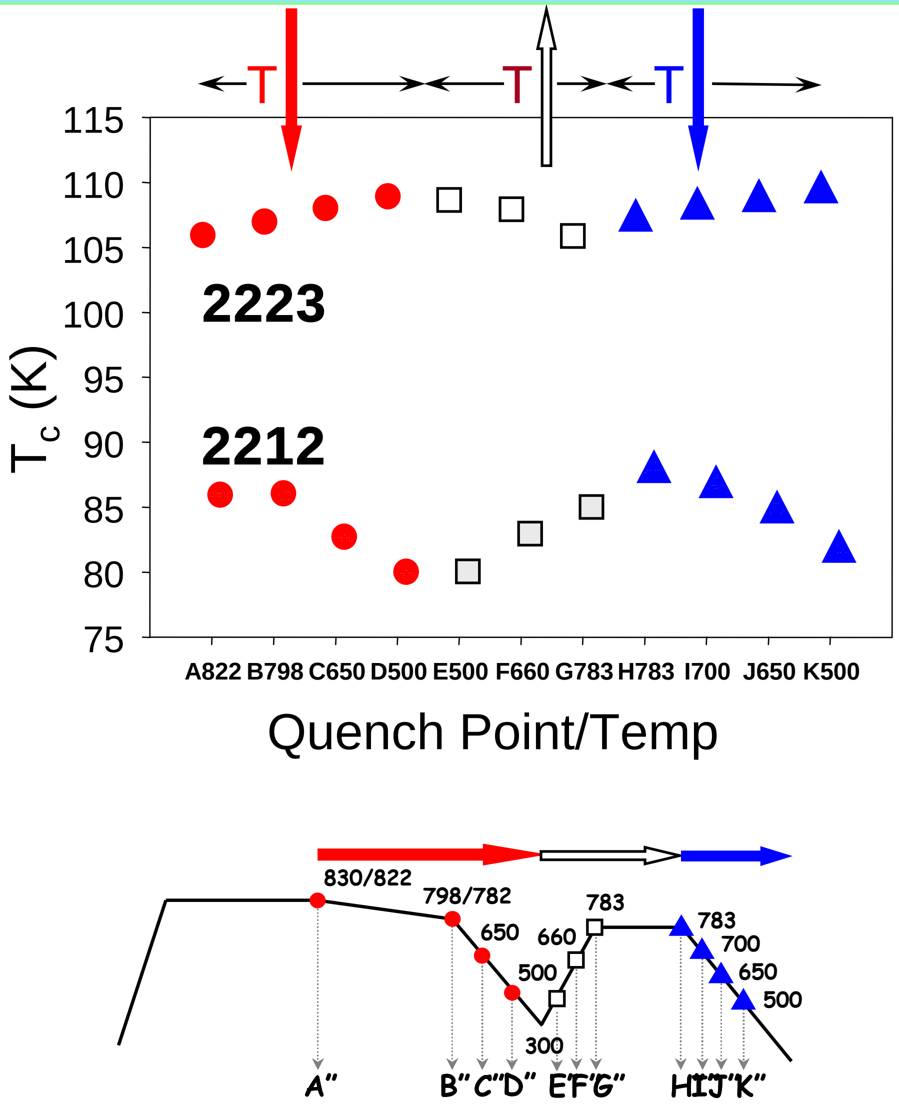
I_c scales with H_K and depends on quench temperature







T_c of 2223 and 2212 change in opposite ways with quenching temperature

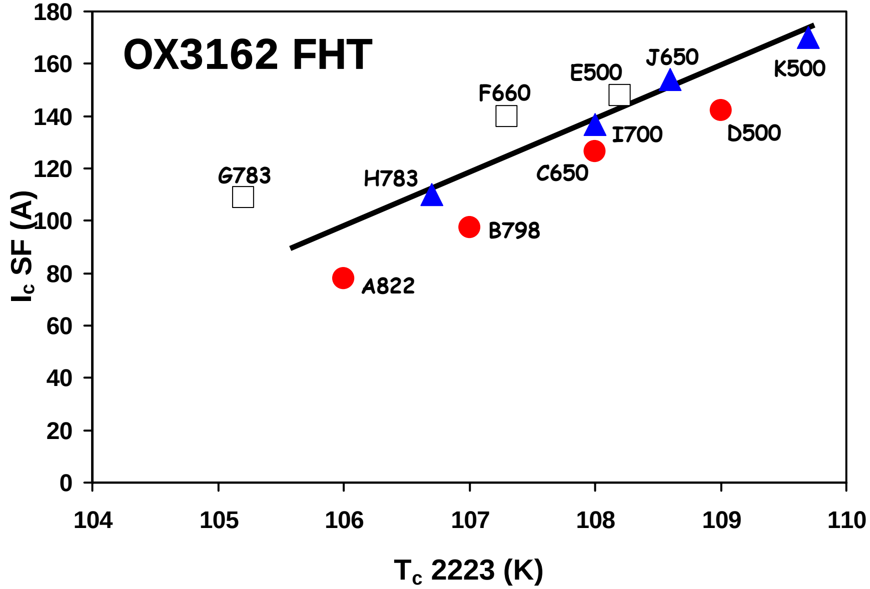


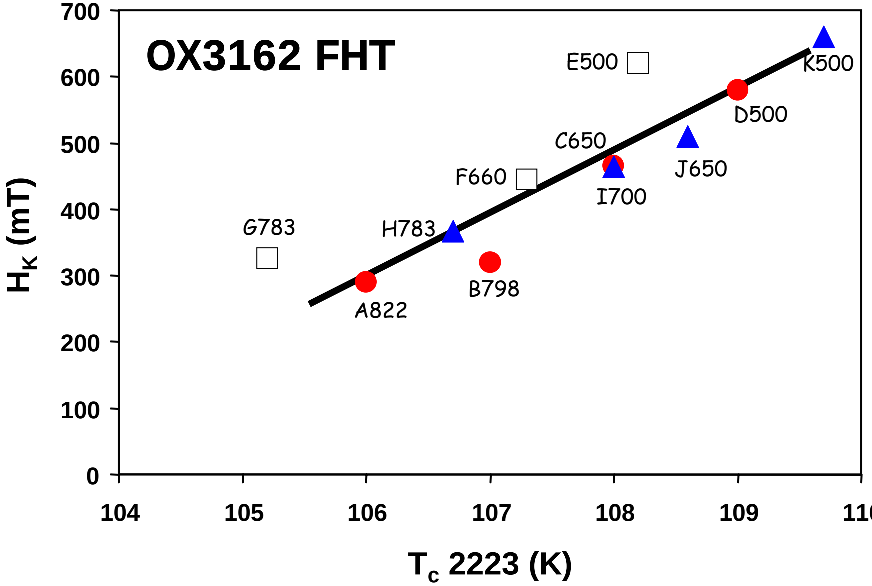
T_c of 2223 and 2212 change in opposite ways with quenching temperature

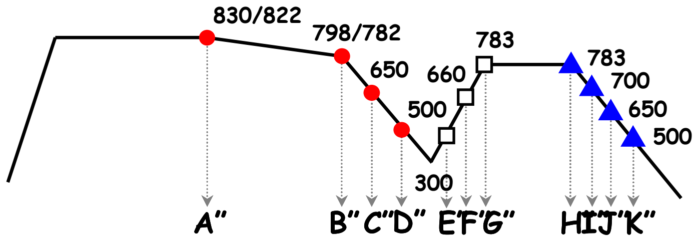
Hypothesis - T_c changes due to oxygen doping

Oxygen doping changes flux pinning

4K increase in 2223 T_c increases I_c by >100% ⇒ Flux pinning







Summary

- OP produces record 202 A Ic
- 2212 reduction is still important
- Post annealing – has major effect on I_c
  - Interplay between:
  - Flux pinning - Oxygen doping affects T_c of 2223 and 2212
  - Connectivity - Liquid redistribution and conversion

Local Understanding of Jc

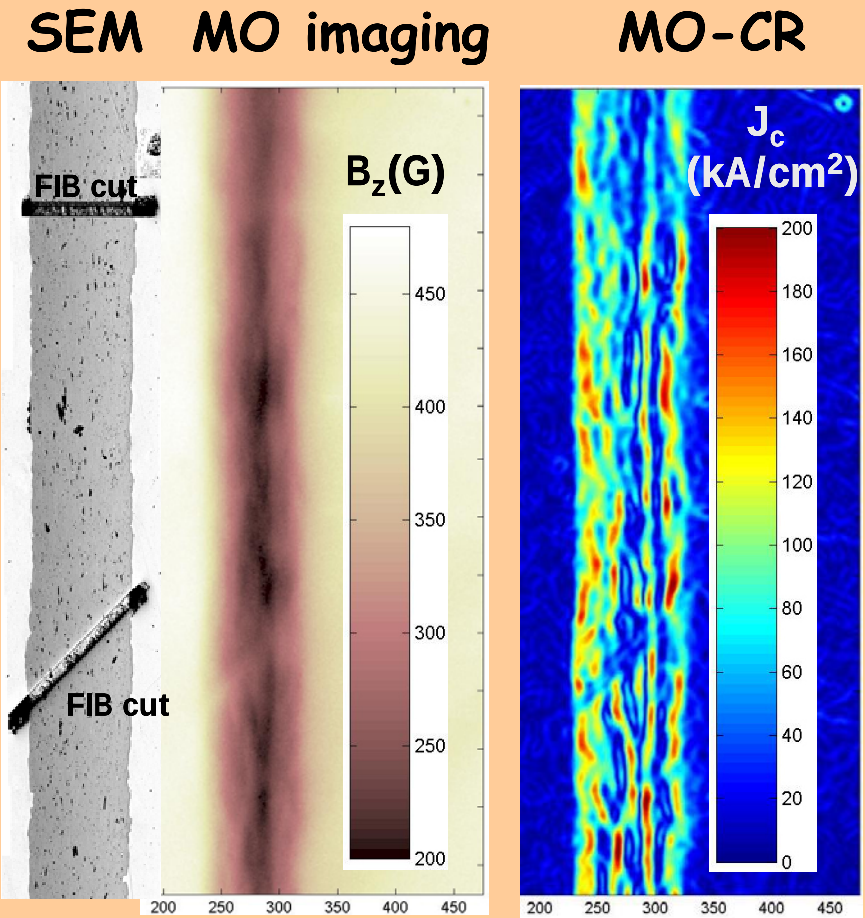
- Why? –
  - Distinguish connectivity from flux pinning limits to Jc
- How?
  - Use local probes to identify special regions of interest
    - Magneto-Optical Imaging (MOI)
    - Low temperature laser scanning microcopy (LTLSM)
    - Through thickness electron backscatter diffraction (EBSD)
  - SEM and TEM on exact local regions of interest
  - Contrast local and global Jc performance
- So what?
  - Develop new processing strategies for higher Ic and Jc

MO-CR to determine local J_c

- Current percolates through many obstacles in Bi-2223 tapes
- Magneto-optical imaging, especially with current reconstruction is the best way to visualize the large local variations
- In 2003 we showed that maximum of Jc was >4 times transport Jc
- 2004:

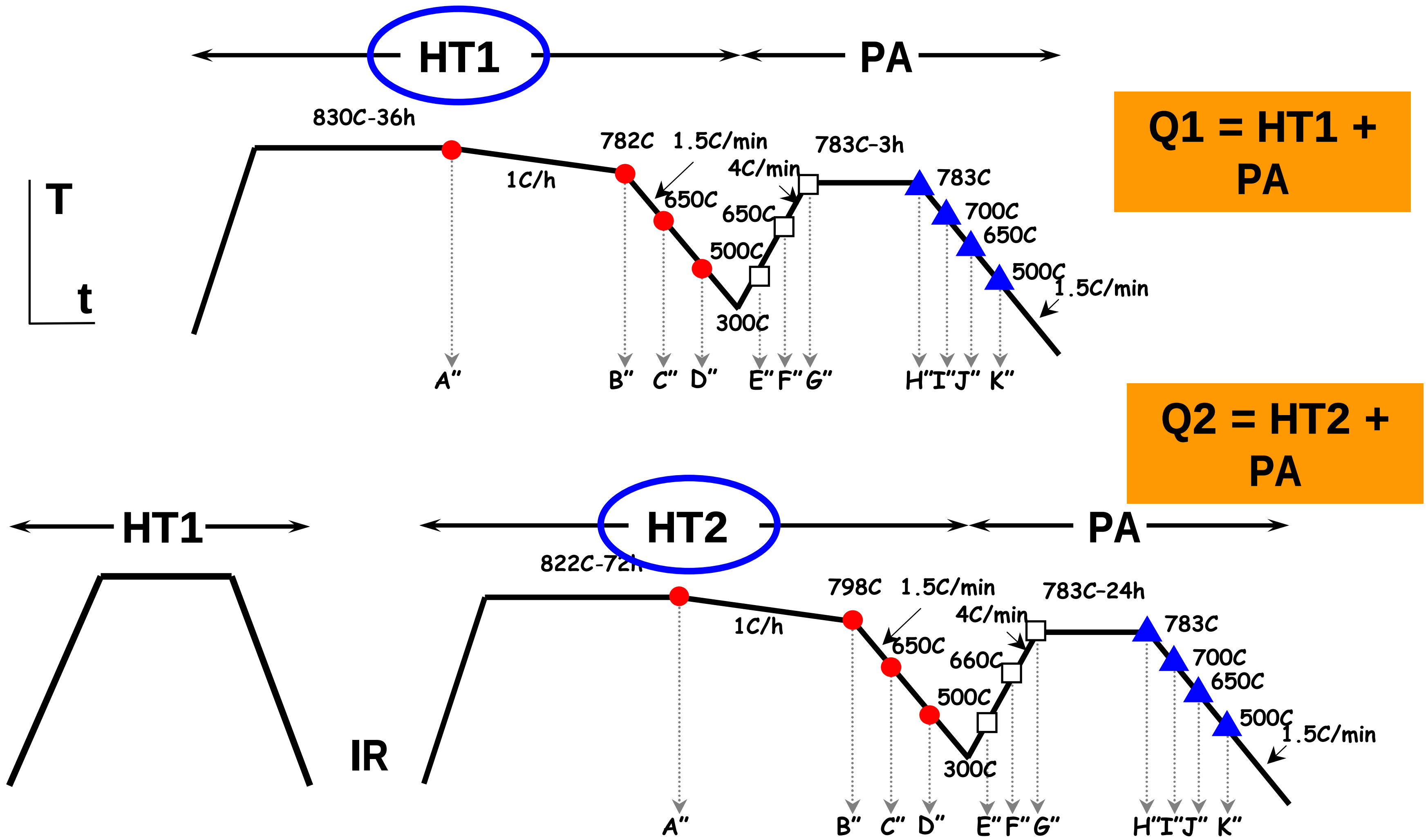
a. Through process study

b. Local determination of current-blocking defects



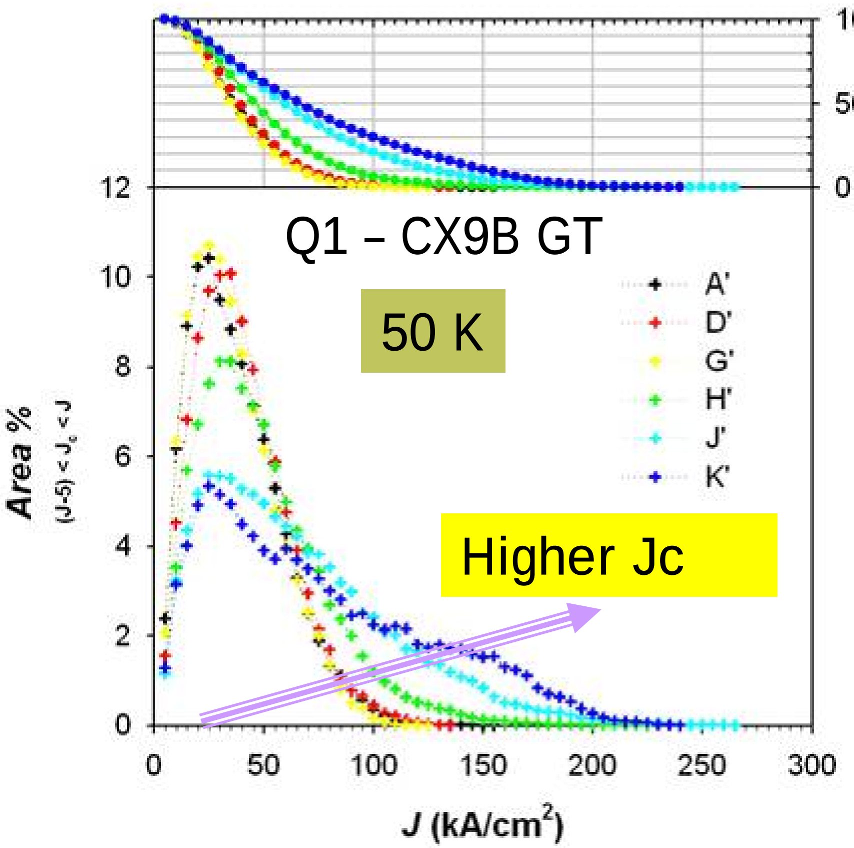
Sample: OP-CX9B-TA2 Bi-2223/Ag
Transport J_c(77K,0T) : 41.3 kA/cm^2
MOI: 77K (ZFC), 45mT (H // ab-plane)

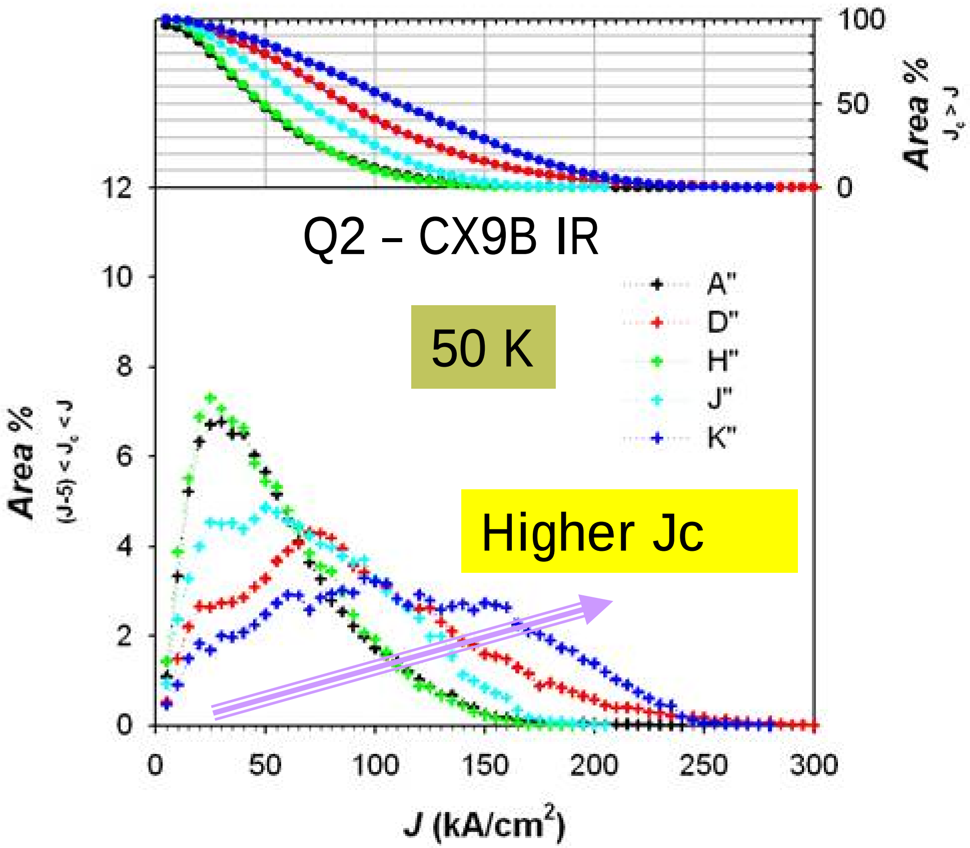
How does the local J_c compare to the transport J_c throughout the process? Through-process quench study.



Ph D thesis work of Yongwen Yuan

PA strongly enhances the Jc distribution



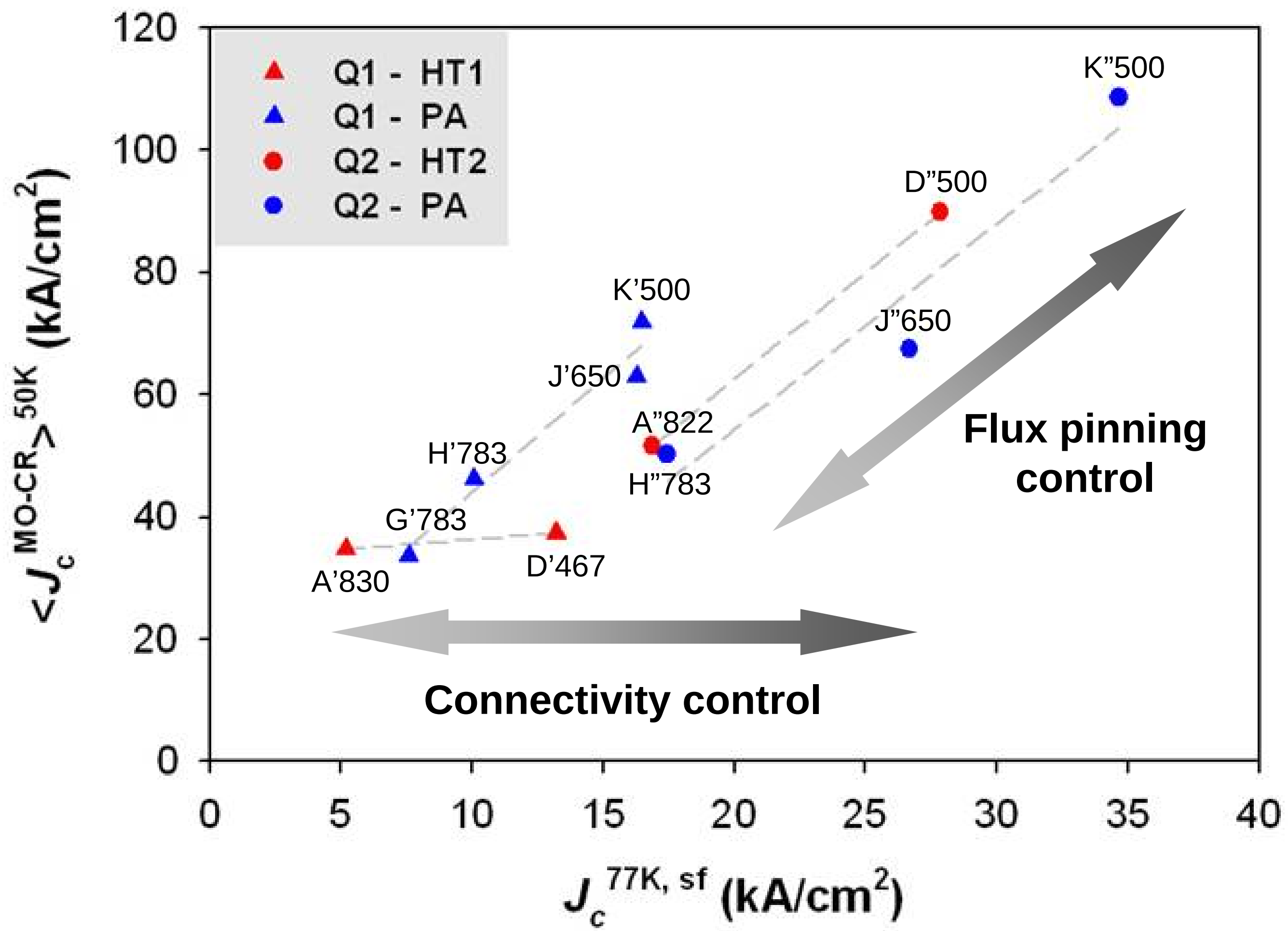


Jc distribution broadens towards higher values

especially during PA for both HT1 and HT2

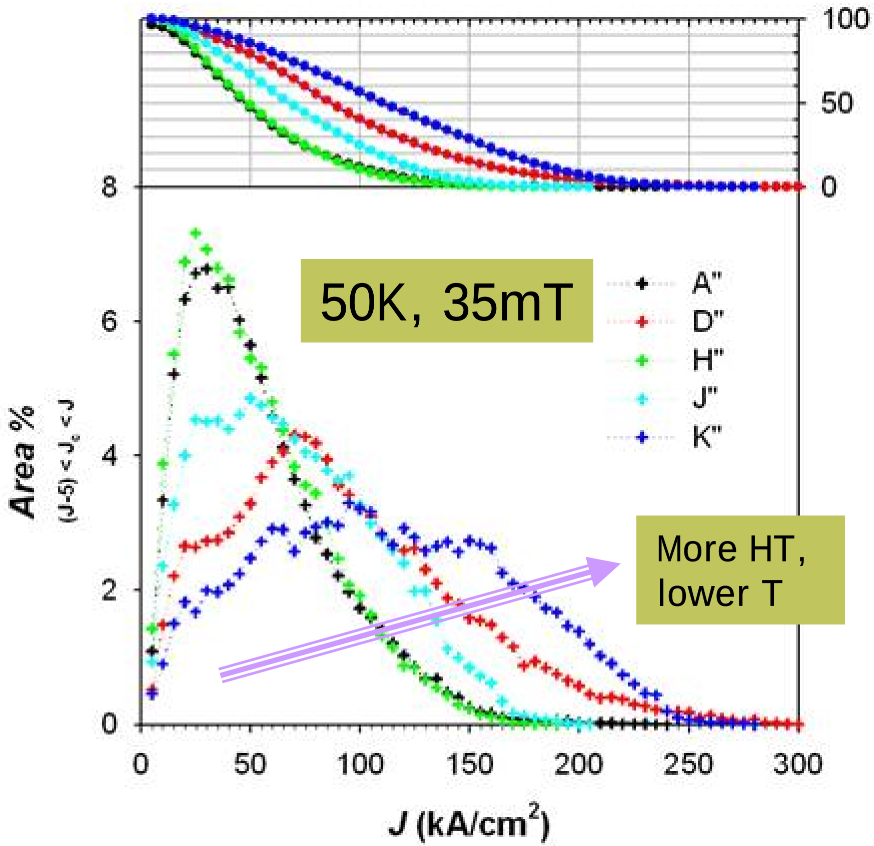
Ph D thesis work of Sandy Liao

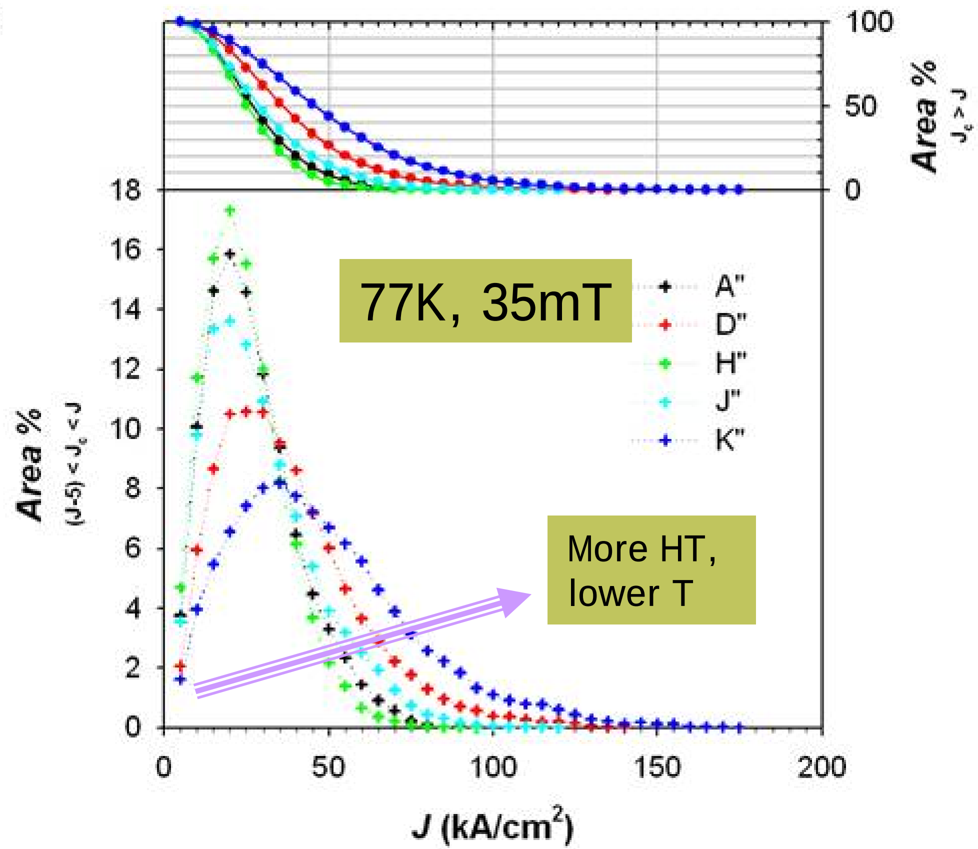
Local versus global Jc



Early in HT1 when much liquid residue is present <Jc> appears flat – later local Jc and transport Jc track well, although <Jc> is always much greater than transport Jc

MO-CR distributions at 50 and 77K



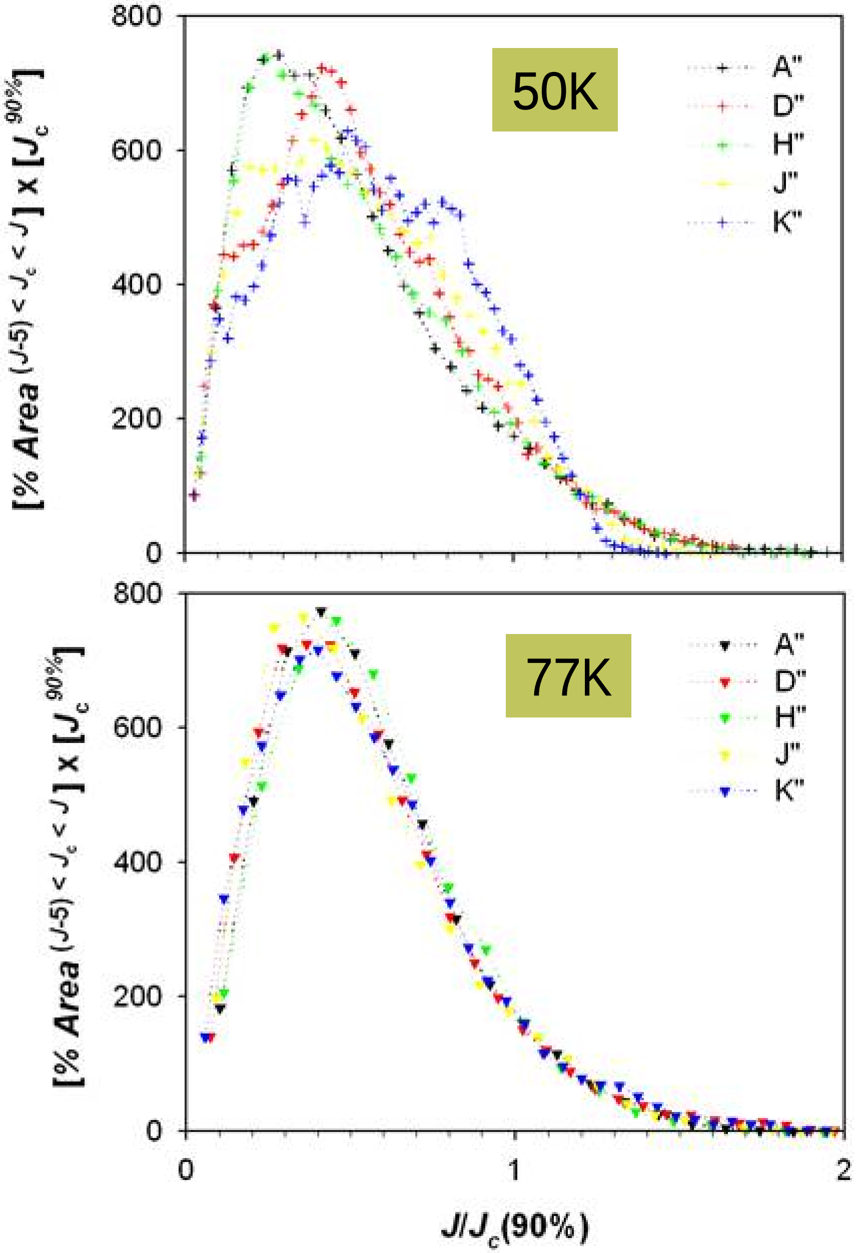


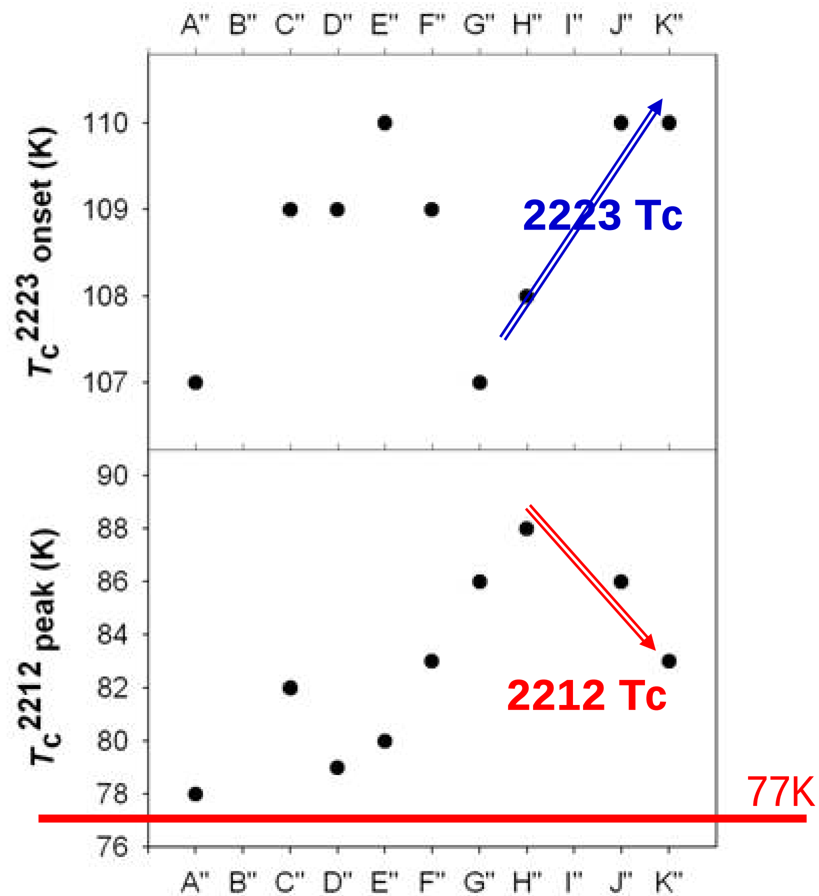
60% of best sample has local Jc > measured transport Jc(77K) of 40 kA/cm^2

The PA raises the upper Jc distribution, not just <Jc>

Jc distribution is more sharply peaked at 77K than at 50K

Can we understand role of residual 2212?

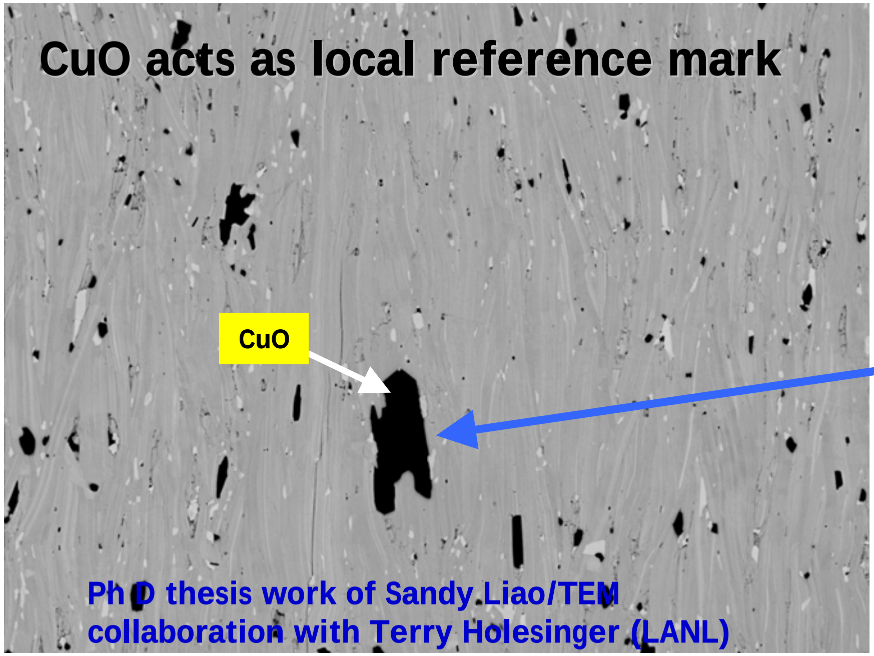


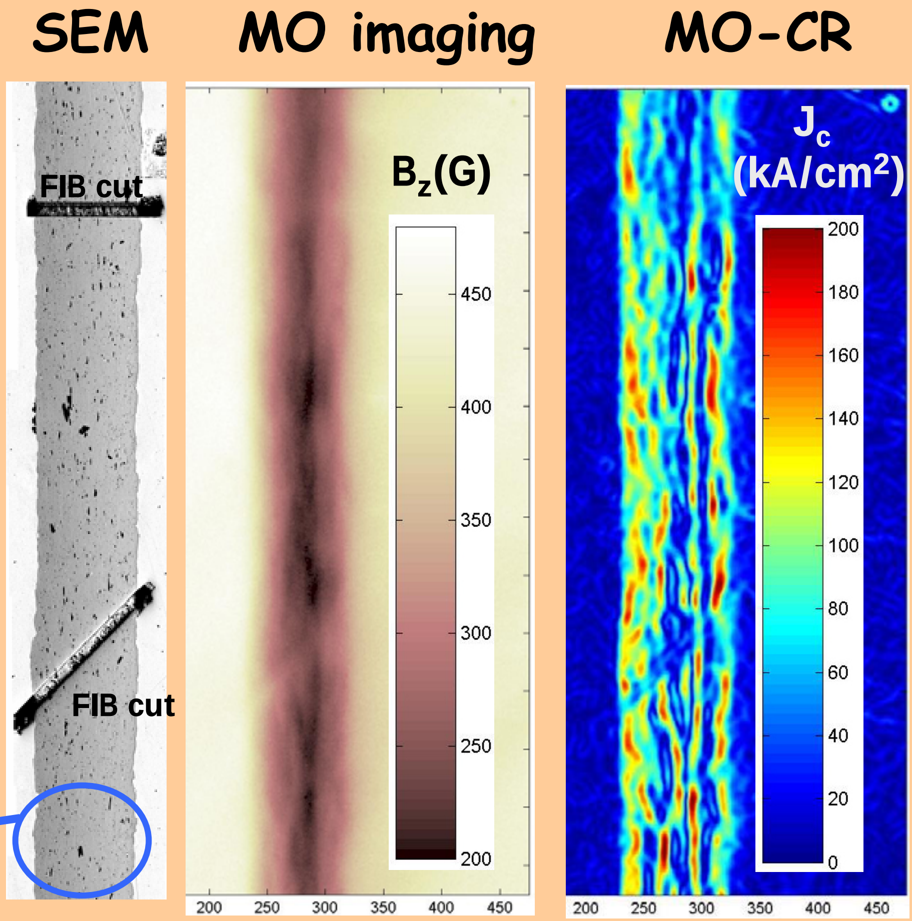


Normalized distributions are self-similar at 77K, but show extra weight at high Jc at 50K, well below Tc of 2212

What blocks the current *locally* in Bi-2223?

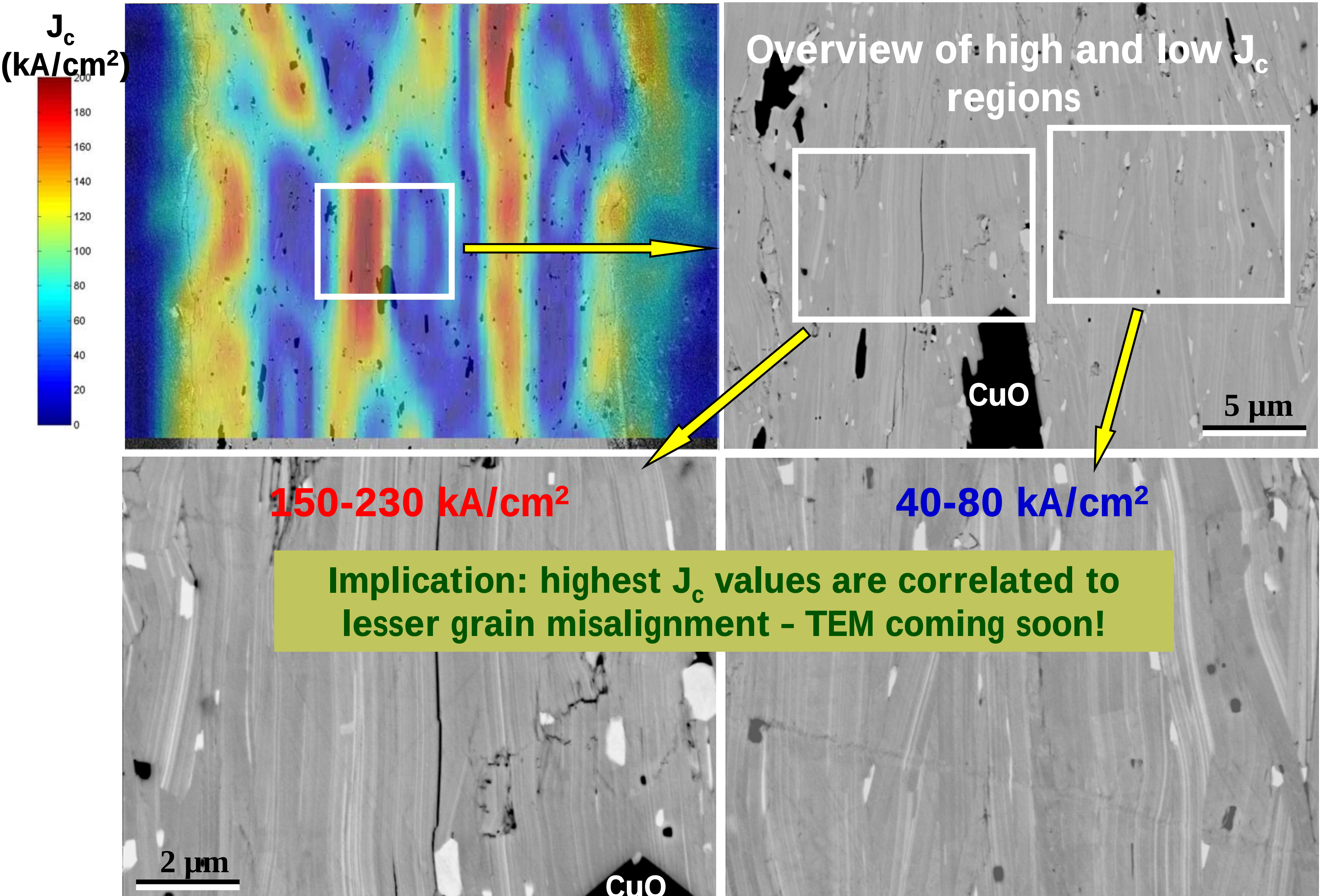
- Identify low and high-J_c areas by MOI
  - Low Jc - 40-80 kA/cm^2
  - High Jc - 150-230 kA/cm^2
- SEM backscatter of both regions
- FIB cutting for later TEM





Sample: OP-CX9B-TA2 Bi-2223/Ag
Transport J_c(77K,0T) : 41.3 kA/cm^2
MOI: 77K (ZFC), 45mT (H // ab-plane)

Low J_c region has more basal-plane termination



Implication: highest J_c values are correlated to lesser grain misalignment – TEM coming soon!

Coated Conductor questions

- How to increase flux pinning? (Civale)
- How thick can YBCO usefully be made?
  - Present industrial optimum is ~ 1μm, ~270A/cm
  - Why does Jc go down as t goes up?
  - Is epitaxy maintained as thickness increases?
- Over what H, T are GBs still obstacles to current?
  - Is misorientation the only variable?

See talk by Holesinger, Feldmann and Feenstra – Thursday afternoon

Sample sets and sources:

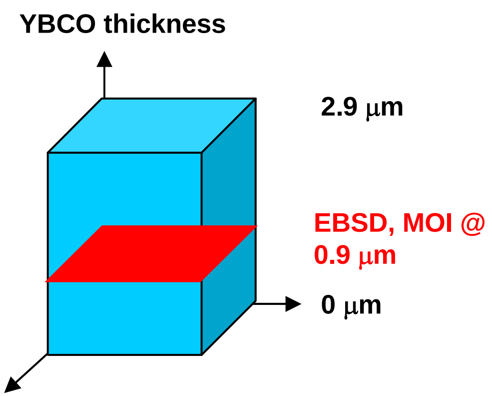
AMSC (~270A and 130A/cm, 1 μm thick, 1.3 and 2.7 MA/cm^2) MOD on RABiTS

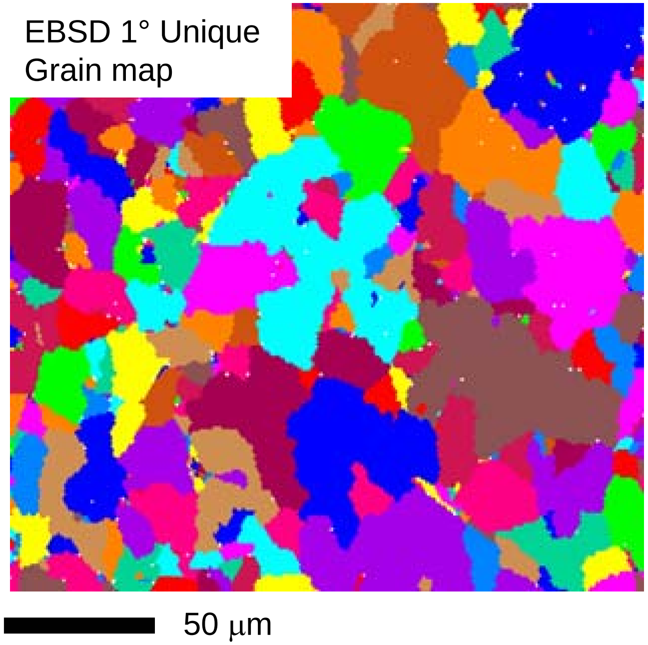
ORNL (Feenstra) 0.3-3 μm thick 1-2.5 MA/cm^2) BaF_2 on AMSC and ORNL RABiTS

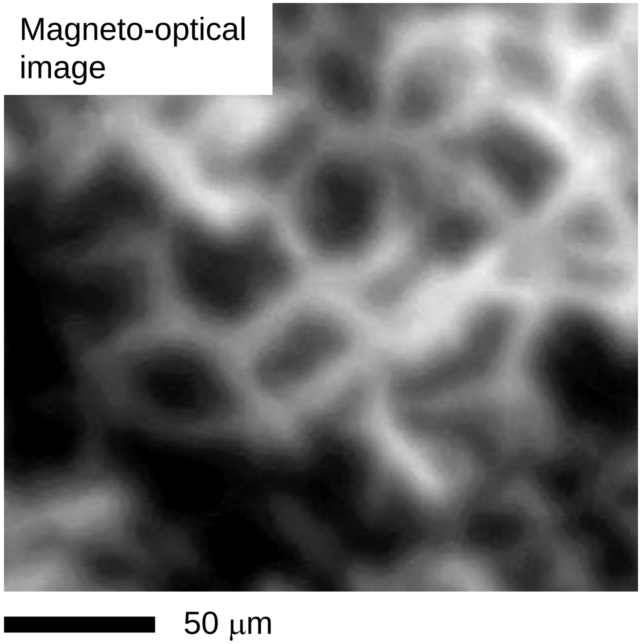
Do the YBCO grains really follow the template?

Liquid-driven growth produces 30-50μm grain size on ~100 nm YSZ!

The template is not determining the grain structure!







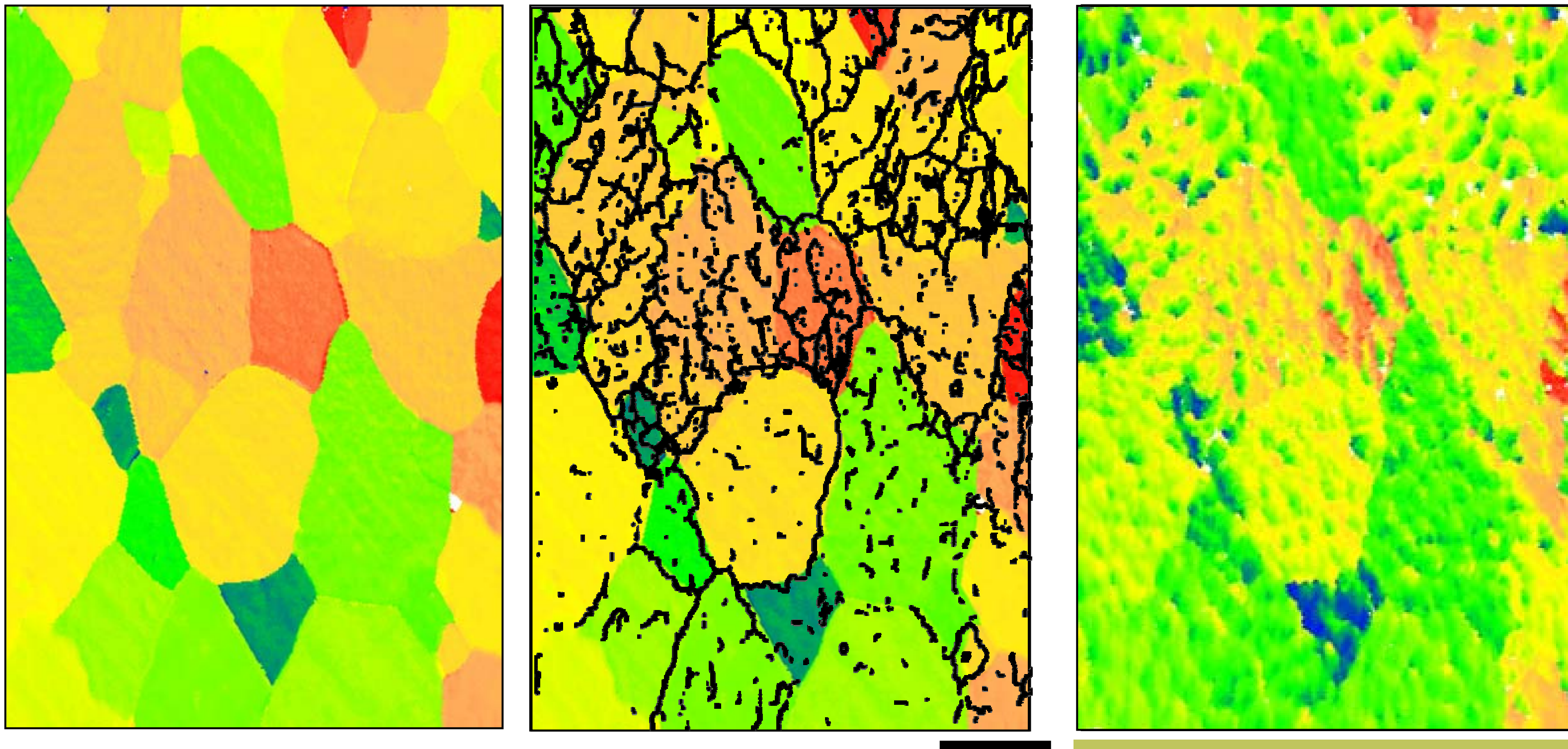
Same sample (different spatial locations)

2.9 μm thick ORNL BaF_2 film at 280A/cm width

Postdoc work of Matt Feldman in collaboration with Ron Feenstra (ORNL) and Terry Holesinger (LANL)

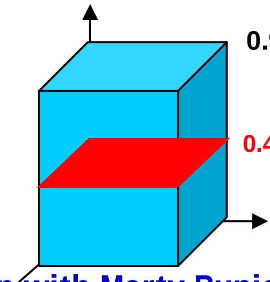
Out of plane YSZ misalignments favor YBCO sub-structure even for 1 μm thick AMSC MOD film

YSZ out-of-plane alignment | YBCO grains on YSZ out-of-plane | YBCO @ 450 nm

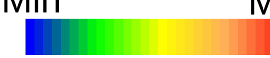


YBCO – $\Delta\phi$ ~5.5°, $\Delta\omega$ ~ 4°

"Redder" YSZ grains are more highly misaligned and have more "black" sub-grain structure (θ>2°)



Angle between sample normal and nearest crystal axis



Postdoc work of Matt Feldman in collaboration with Marty Rupich (AMSC)

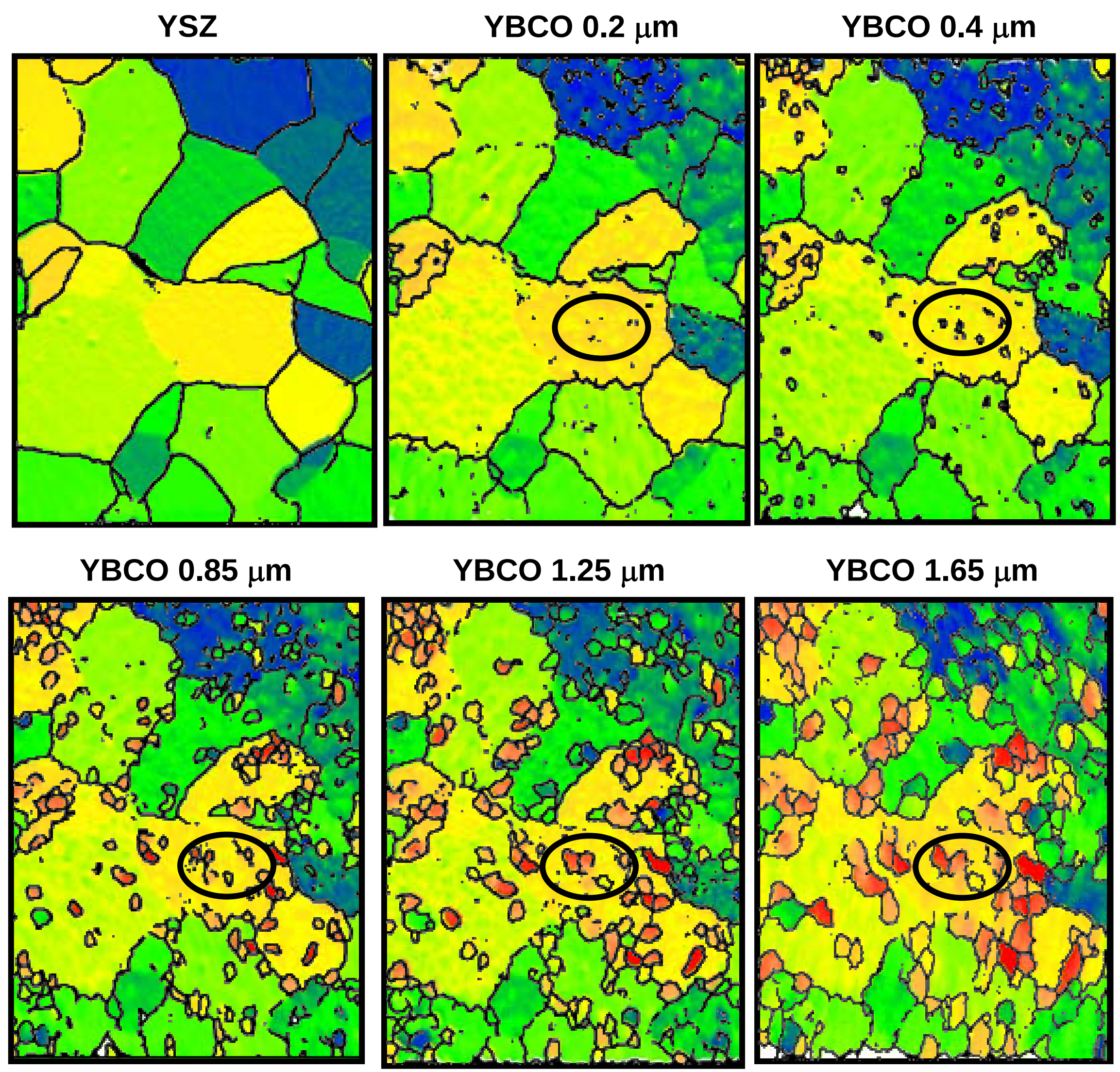
Grains within grains: 1.8 μm thick BaF_2 film on AMSC RABiTS

GBs marked for $\theta \geq 2°$

Angle between sample normal and nearest crystal axis

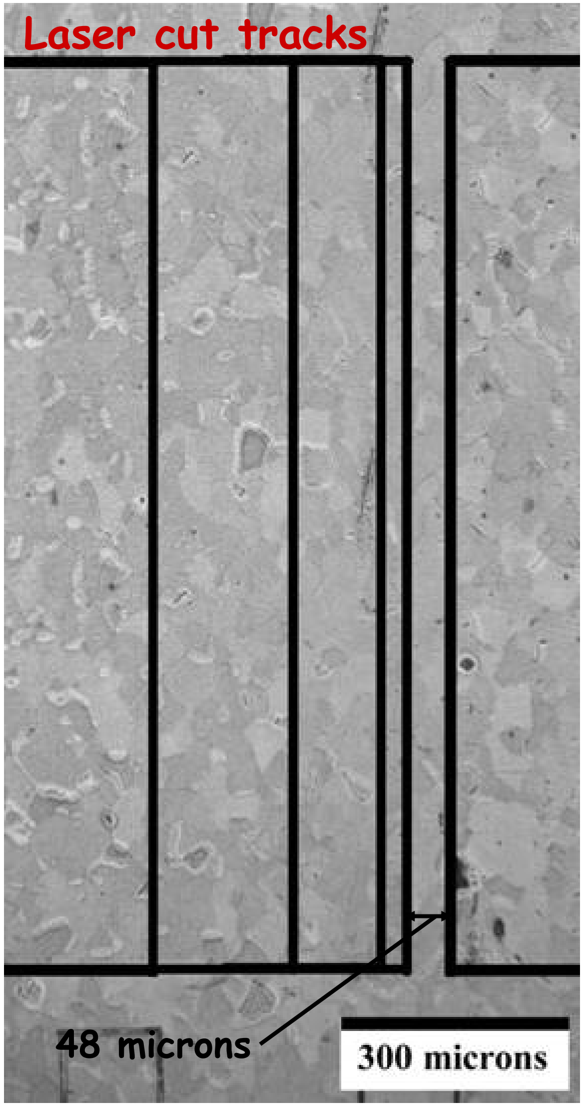
Conical grains seeded from misaligned template grains develop larger $\Delta\theta$

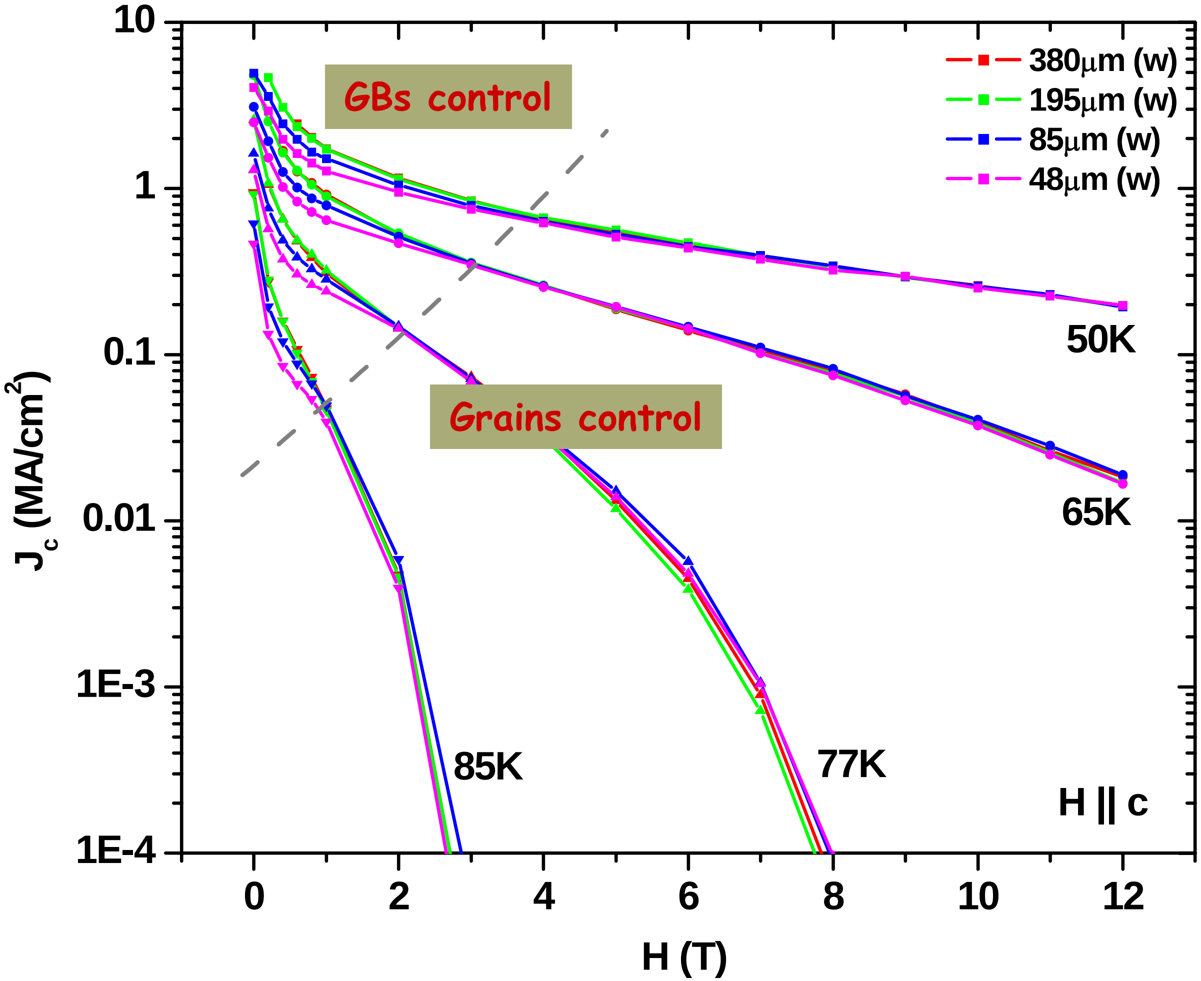
But **Ic is >300 A/cm**



Postdoc work of Matt Feldman in collaboration with Ron Feenstra (ORNL) and Terry Holesinger (LANL)

Do GBs still limit Jc in low FWHM CC?

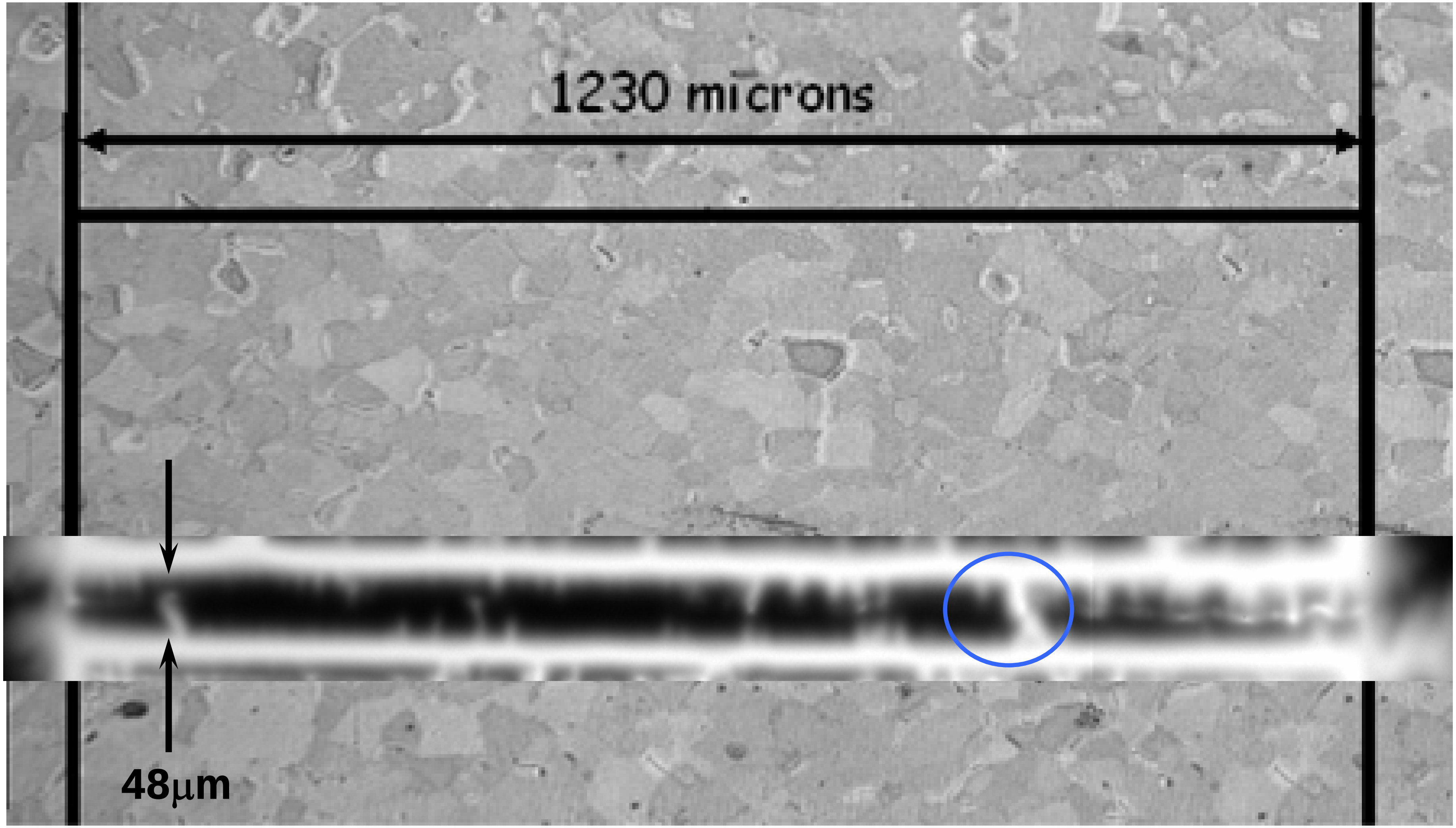




270 A/cm at 2.6 MA/cm^2 TFA on RABiTS

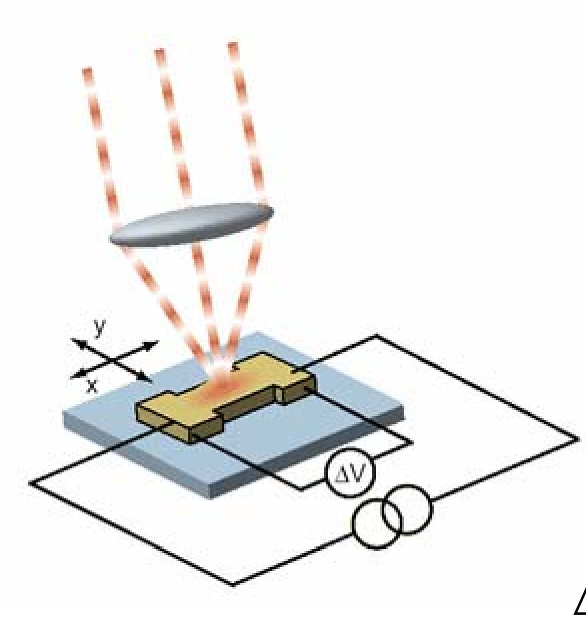
PhD thesis work of Sang-Il Kim in collaboration with Darren Verebelyi and Cees Thieme (AMSC)

One GB only limits Jc in this track

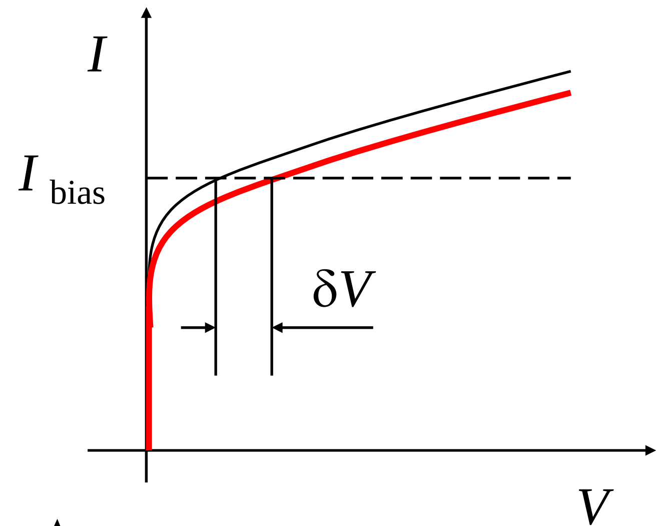


EBSD (on Ni-W, not YBCO) – the MO-visible GB has θ 7-9°, perhaps 5-7° on the YBCO

Low Temperature Scanning Laser Microscopy



$$\Lambda_{ac} = \frac{\Lambda_{dc}}{\sqrt{\omega\tau}}$$



$$\Delta P \rightarrow \Delta T(x_l, y_l) \rightarrow \begin{matrix}\Delta\rho \\ \Delta j_c\end{matrix} \rightarrow \delta V(x_l, y_l)$$

$$\boxed{\delta V(x_l, y_l) \approx -\frac{\partial J_c}{\partial T}\frac{E(x_l, y_l)}{J_c} 2n\Lambda\delta T}$$

Focus scanned laser beam on CC surface with simultaneous recording of the electrical or/and optical response.

C.C.Chi, M.M.Loy and D.C. Cronemeyer, *Appl. Phys. Lett.* **40,** 437 (1982)

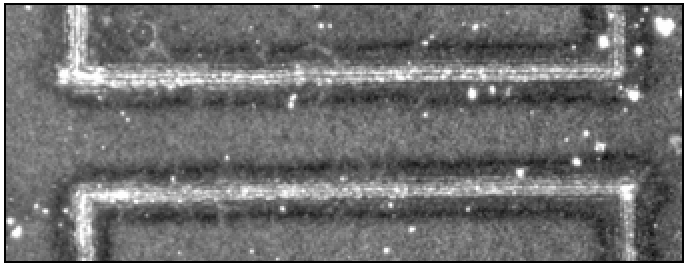
M. Scheuermann, *et al, Phys. Rev. Lett.* **50,** 74 (1983)

V.A. Konovodchenko, A.G. Sivakov, A.P. Zhuravel' *et al, Sov. J. Low Temp. Phys.* **12** , 311 (1986)

Postdoc work of Dmitri Abraimov

LTLSM shows significantly better resolution than MOI

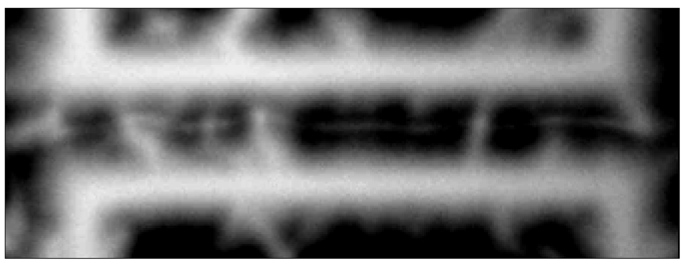
Photo image



100 μm

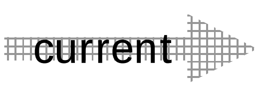
60 μm wide bridge

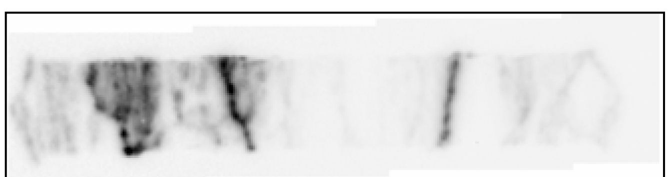
MOI image



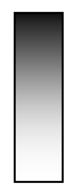
T=11.6 K
Zero Field Cooled image
H=100 mT

LTLSM voltage response





22 μV

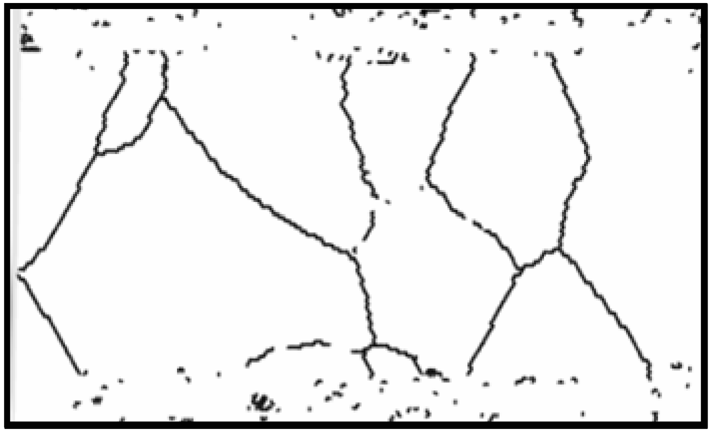


0 μV

T=78.9 K
Bias point: I=287 mA
<V>=734 μV
Scanning step 0.5 μm

Details of current flow revealed by LTLSM

EBSD on Ni - YBCO 2-3° less



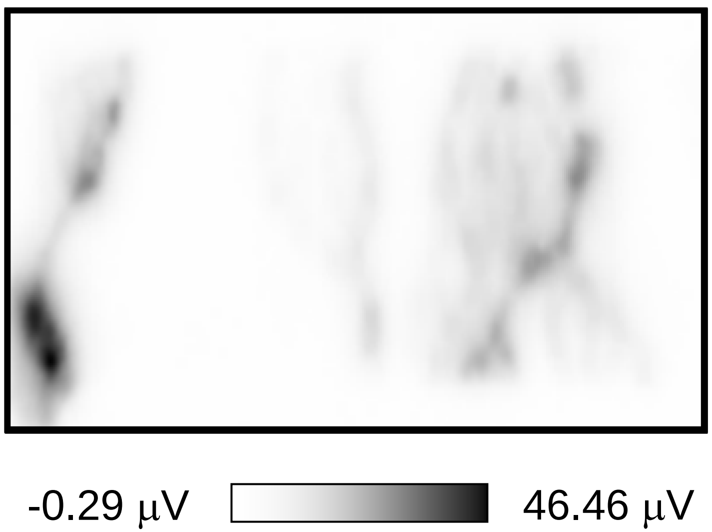
$\theta \geq 2°$

Large 7-9° GB segment focuses current through the lower angle GB

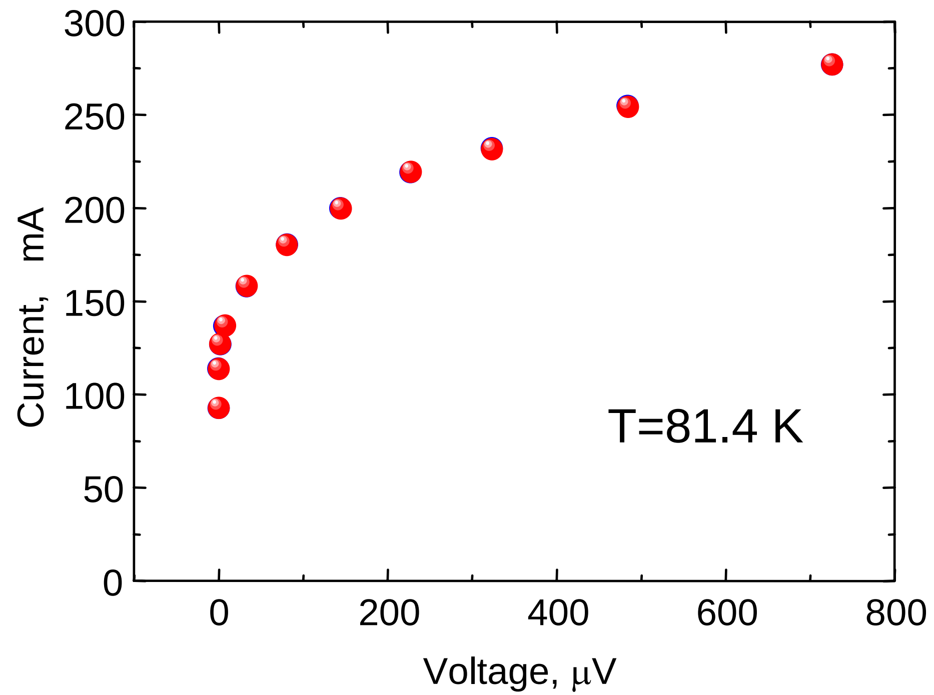
Dissipation is never uniform even at many times Ic

30 μm

LTLSM voltage response



-0.29 μV 46.46 μV



Local probes - Summary

- MO-CR shows:
  - Large headroom in Bi-2223 Jc throughout the process
    - Final post anneal shifts Jc weight to even higher Jc
    - Connectivity loss in lower-Jc regions associated with strongly misaligned grains
- LTLSM is almost ready – collaborations show:
  - Spatial resolution several times better than MO-CR
  - Works in transport – and in field!
  - Shows strong local variation of dissipation at GBs – and within grains too?
- Orientation mapping by EBSD is a very powerful adjunct to all techniques
  - Shows unexpected degradations of epitaxy as films thicken
- Local track studies of CC show unexpectedly few blocking GBS even for tracks some 10 grains long and 1 wide
  - Most CC applications are still in the GB limit

WDG FY04 Performance - I

Plans	Performance
1. Improve understanding of 2223 formation process in its full complexity	**1. Focused on final process stages, launched quenching studies with full array of characterization; co-ordinated and applied to AMSC R+D process**
2. Evaluate alternative routes to higher 2223 phase purity (new powder, alternate HT profiles) and evaluate their Jc potential	**2. Put on hold due to budget cuts**
3. Understand current limiting mechanisms at more local scales: develop LTSLM	**3. Developed laser scanning tool; used Erlangen facility of Prof. Alexey Ustinov while UW equipment was being built**

WDG FY04 Performance - II

Plans	Performance
4. Explore viable ways to make OP work in production (AMSC, UW)	4. **Refocused work on revised goal of using OP to reach higher Ic. Work limited by budget cuts.**
5. Initiate 2G work – pinning and GB effects characterization and optimization	**5. WDG participation expanded to address 2G issues with new participants – Feenstra (ORNL) and Civale (LANL). Exploited commonality between BSCCO and YBCO studies.**

WDG FY04 Performance - III

Plans

6. Understand and enhance flux pinning in coated conductors

Performance

6a. Field and angular dependence studies of flux pinning at LN and/or LHe temperatures have been performed on several MOD-based CC, and contrasted with PLD.

6b. TEM was used to investigate structure and correlate with pinning.

WDG FY04 Results - I

Plans	Results
1. Improve understanding of 2223 formation process in its full complexity	**1.** ✓ **UW quench studies of final heat treatment steps identify new current enhancement mechanism - 2223 T_c increase competing with effect of reduced 2212 T_c** ✓ **New method of identifying T_c of 2212 in 2223 developed** ✓ **AMSC uses this information to achieve new short length 1G record without OP - 190 A (77 K) and >1000 m 148 A production wire**
2. Evaluate alternative routes to higher 2223 phase purity (new powder, alternate HT profiles) and evaluate their Jc potential	**2. Put on hold due to budget cuts**

WDG FY04 Results - II

Plans	Results
3. Understand current limiting mechanisms at more local scales: develop LTSLM	3. ✓ **Find that resolution of LTLSM is better than MO – enables dissipation within local 2G grain to be observed**
4. Revised goal: Use OP to achieve higher Ic	**4.** ✓ **UW achieves new 1G record 202 A (77 K, sf) on AMSC precursor**

WDG FY04 Results - III

Plans

5. Initiate 2G work
   – pinning characterization and optimization

Results

- ✓ **Field-angle Ic characterization and TEM at LANL on AMSC 2G wire reveals correlated pinning from planar grain structures dominate**
- ✓ **Technologically relevant regime $Jc \propto H^{-\alpha}$ identified**
- ✓ **Nanodot pinning identified by LANL field-angle I_c and TEM in AMSC ex-situ Y and Ho-doped 2G wire**
- ✓ **ORNL achieves reduced field-angle I_c dependence in ex-situ 2G wire with shortened process time**

WDG FY04 Results - IV

Plans

5. Initiate 2G work
   - grain boundary characterization and optimization

Results

- ✓ **UW establishes the field and temperature domain of grain boundary limitation of J_c: covers range of most power applications**
- ✓ **ORNL and UW find meandering and through-thickness angling of grain boundaries to be widespread in ex-situ 2G samples from both AMSC and ORNL. Some evidence shows that this effect may diminish grain boundary current-limiting effects**

WDG Technology Integration

- The WDG is team-focused; now in its 14th year!
  - AMSC, ANL, LANL, ORNL, and UW synergistically working together
  - Added CC component in past year (Civale – LANL, Feenstra – ORNL)
- Three technical meetings a year define the work plan
  - Off-line collaborations keep work going between meetings
  - Graduate students are integrated into the work at ANL, ORNL, and UW
  - Outside collaborations further enhance the work (LTSLM-Ustinov/U. of Erlangen, Germany)
- Leveraging of effort is strong
  - AMSC 1G tape – the best in the world – common source for most BSCCO experiments
  - AMSC 2G tape - a world leader in R&D 2G tape – common source for many CC experiments

WDG 2005 Research Plans

1G: Bi-2223

- Build on new understanding of the post anneal to enhance 2223 Tc effects without countervailing 2212 Tc effect
  - Use through-process study with local registration of MO image and microstructure to understand the separate contributions of flux pinning and connectivity to J_c - apply LTLSM too
- Develop new strategies for better approaching an all-2223 phase state
- Achieve further increases in over-pressure processed 1G wire

2G: YBCO-CC

- Build on improved understanding of pinning mechanism in 2G wire to optimize pinning and further reduce the field-angle dependence
- Characterize grain boundary meandering in thick (>1 μm) 2G films and understand its effect on the grain boundary current density
- Understand relation of local blocking of current by grain-boundaries to global texture using ~1 μm resolution of LTLSM

WDG will continue to accelerate HTS wire performance progress, enabling improved production wire for applications